

WORLD COFFEE DYNAMICS

A THESIS

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By

Raul Serna-Laignelet

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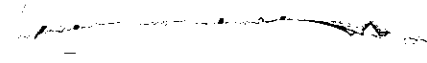
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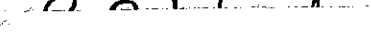
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## WORLD COFFEE DYNAMICS

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## CHAPTER I

### INTRODUCTION

The unstable performance of the world coffee economy has been a subject of controversy. The coffee literature describes coffee cycles of eight, ten, twenty or more years, invariably attaching 'cobweb' explanations to them. There are too many postulated cycles to fit just one description. The lack of precise descriptions of the fluctuations in coffee production and prices presents a great obstacle to effective stabilization policies.

The purpose of this research is to study the behavioral characteristics of the long and intermediate cyclic movements generated by the world coffee system. In particular, this study establishes conditions under which stability could be attained.

This thesis presents evidence that the behavior of the world coffee economy displays three different types of cyclic movement:

- (1) A long cycle of around thirty two years in duration, intertwined with a sequence of harmonic cycles of shorter period, about sixteen, eight and four respectively. These cycles originate in the Coffee Production Sector. This sector contains a long chain of time delays whose effect is to shape the major cycle of 32 years. The research shows that the abandonment of older trees when prices fall, causes the existence of a lagged harmonic of sixteen years; in turn, the tendency of the farmers to upgrade their

cultivation procedures when prices are high, causes the appearance of other harmonic of eight years.

- (2) An intermediate range cycle of around six years in duration. This cycle originates in the Coffee Trade Sector.
- (3) Two short-term movements; one of about two years, i.e. the biological cycle of the coffee tree; the other with a period of more than three years in duration. The three year cycle appears to produce far more influence on behavior than the two year cycle. This research does not study the nature of these two short-term movements.

The 32 year composite price wave exhibits unstable performance. This research shows that the long delays contained in the coffee production sector, together with a tendency of the system to accumulate obsolete capacity and a poorly conceived supply policy are major causes of the unstable performance of world coffee prices, output and stocks. This thesis presents evidence that a supply policy based on exportable production plus or less whatever is required to maintain a target level of stocks is a counter stabilization policy.

The research shows that the implementation of International Coffee Agreements to enforce a system of export quotas does not stabilize the long run performance of coffee prices and output. Similarly, the establishment of an International Buffer Stock to control world prices does not render the intended price stabilization.

The research suggests, on the other hand, a major change in the supply policy of the producer nations to generate stable price patterns. The new policy

requires a departure of the traditionally entrenched mechanisms which establish the amount supplied at the market place. Thus, the quantity supplied should depend on the annual consumption rate (at the end consumer level) not on annual exportable production; secondly, producers should use a very slow stock adjusting mechanism to achieve their inventory target.

The six year coffee cycle is caused by a too rapid inventory adjustment policy at the trade and distribution sectors. Preliminary research on the behavior of both hedgers and speculators in the coffee future market indicates that this market is a major cause of the unstability exhibited by this type of movement. Nevertheless, the operation of a future market brings benefits to traders and users of the commodity. A hedger who routinely maintains a short position is able to operate his business with lower inventory investment than the user who does not trade futures in the market.

Figure I-1 presents a summary of the feedback dynamics model constructed in this research to simulate the world coffee economy.

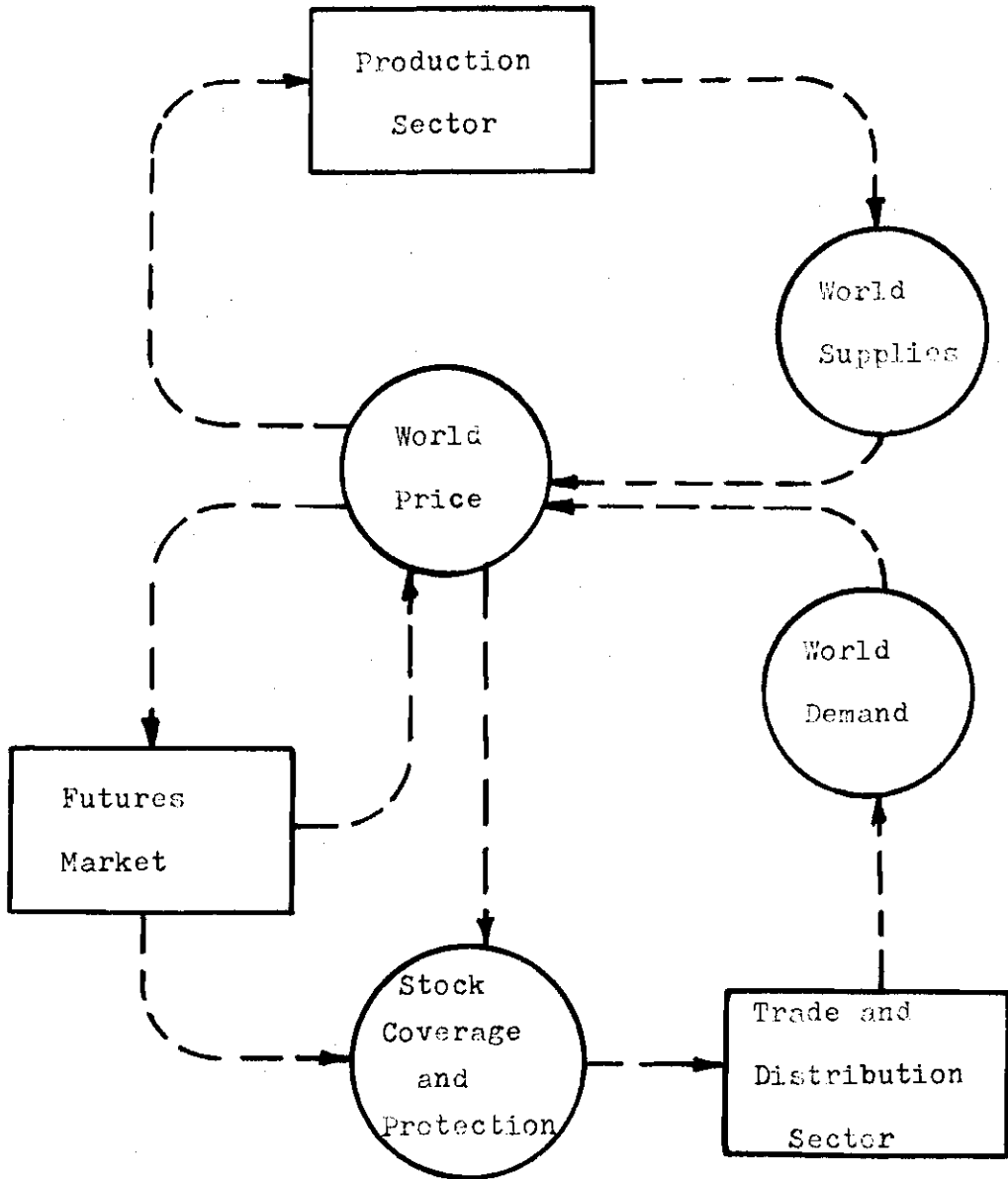


Figure I-1. Summary of World Coffee Model.

## CHAPTER II

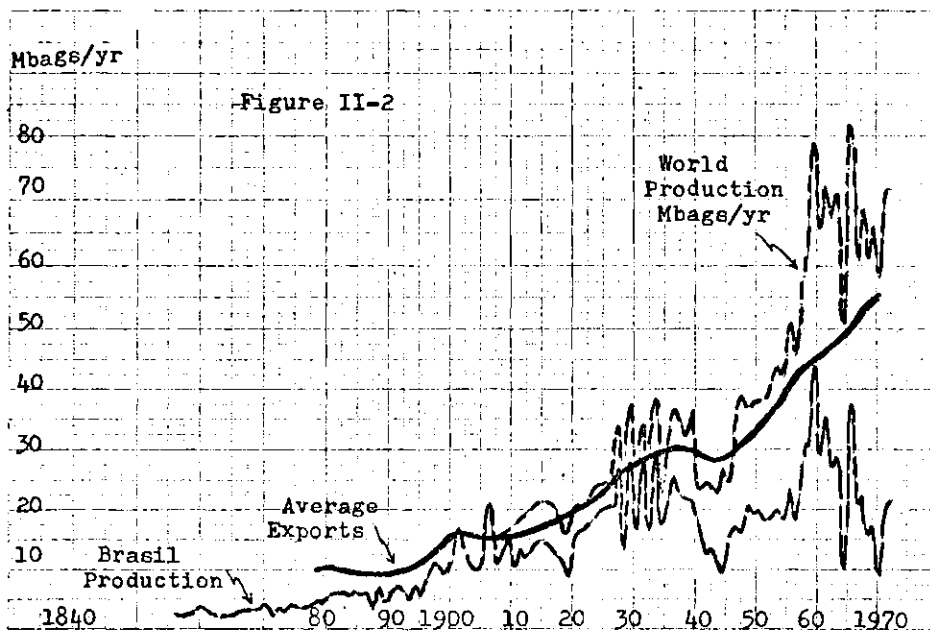
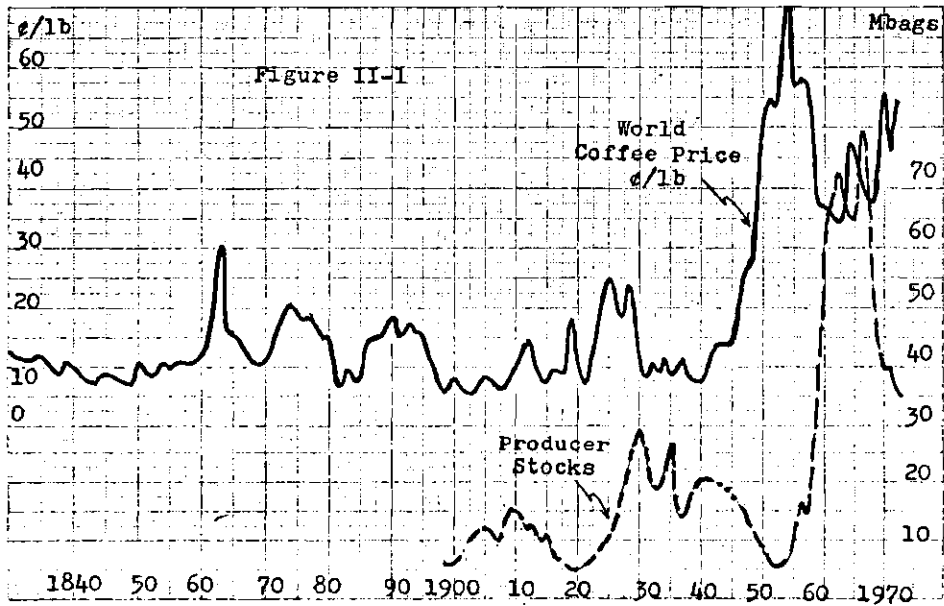
### DESCRIPTION OF THE WORLD COFFEE ECONOMY

The first part of this chapter describes the behavior and main characteristics of the world coffee economy. The last two sections briefly summarize the policies most frequently used by producers in their efforts to stabilize world prices.

#### A. World Coffee Dynamics: Cycles and Oversupply

The world coffee market exhibits unstable performance. World prices and output show long cyclic behavior and wide short-term fluctuations (Figures II-1 and II-2). The pattern of prices displays a complex wave of varying period and amplitude; the stronger peaks, however, seem to repeat at intervals of twenty or thirty years. During a period of rising prices, productive capacity expands and output tends to increase. Several years later stocks rise, reach a maximum and prices fall. Despite the reduced coffee income to individual growers, planted capacity is not rapidly corrected to meet consumer needs; it takes about ten years of low prices to reduce the growth in production, a period during which inventories are built up as much as the equivalent of a year of world usage.

When prices fall, farmers reduce planting rates, abandon a portion of the trees or uproot a fraction of the older, low yield plants. Output then tends to fall. Furthermore, the large producers, acting independently or jointly, restrain



Figures II-1, II-2. Behavior of the World Coffee Economy.

exports and destroy large quantities of stocks, much of which is of poor quality after four years of storage. The reduction in output and the destruction of stocks tends to deplete inventories. Stocks and prices move oppositely, in general (Figure II-1).

Stocks of green coffee tend to rise fast, reach a plateau, and then fall at a lower rate. Therefore total world output tends to be more sensitive to a rise than to a fall in prices. The time to build maximal stocks lasts about eight or ten years, a period longer than the five years the coffee tree requires to mature and produce. Thus when prices fall and planting rates decay, the removal of obsolete capacity is not accomplished in the same proportion, and the stock of trees may continue to grow. In fact, output tends to peak about eight years later than prices, generally when prices have already reached low values.

Consumption of green coffee does not grow at the same rate as exportable production and does not exhibit such severe oscillations. Demand for coffee is unresponsive to world prices except at extremely low or high price levels. Coffee consumption is more sensitive to population growth, availability of substitute drinks and consumer tastes than to price movements.

Most authors regard the long years required to adjust productive capacity to consumer needs together with the low sensitivity of output to price changes as the major cause of the unstable performance of the world coffee industry. If the world coffee market were competitive enough with a large number of producers and buyers, if producers were free enough to enter and leave the market as they please with no government intervention, and if accumulation of inventories were

to play no role in establishing price, then the cyclical instability of coffee could be explained as the direct interplay of supply and demand, as hypothesized by the cobweb model. Unfortunately, few if any of the cobweb assumptions hold for the coffee industry [43], and an explanation of the unstable performance of the coffee industry requires the development of a more complete model. To construct such a model is the main object of this research.

## B. Brief Description of the Characteristics of Coffee Production

### 1. Productive Cycle of the Coffee Tree

The coffee plant requires from four to six years to mature and transform into a productive tree. Thereafter, the yield of the tree increases rapidly until the tree is about ten years old, stays at a maximum for several years and then gradually declines. By the time the tree is forty years old, its annual yield is roughly one third of its maximum annual yield. It is not unusual to find trees one hundred years old still producing but their yield is very low.

Figure II-3 shows a yield pattern frequently found in certain regions of Brazil [1] and in general typical of world coffee production. Although the yield of the coffee tree is primarily determined by the age of the tree, several other factors affect the pattern shown in the figure. First, the tree is subject to a biological cycle that causes alternating years of high and low yield. Second, the different types of seeds produce different age-specific yield patterns <sup>1)</sup>

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<sup>1)</sup> There are three main types of coffee seeds: Milds, produced in Columbia and Central America; Arabics, produced in Brazil; and Robustas, produced in Africa. In turn, there are several varieties within each one of these groups



Third, the returns per hectare depend upon the type of soil and fertilizer used. This is particularly true in the case of the older plants. Fourth, trees with adequate shading and proper cultivation procedures tend to produce higher annual yields. Finally, recurrent but unpredictable frost and droughts have a strong impact on production levels.

All of these factors, among others, affect the yield pattern of coffee. Nevertheless, the pattern exhibited in Figure II-3 appears to be, on the average, a proper description of the productive life cycle of the coffee tree.

## 2. Technological Innovations, Obsolescence and Abandonment of Coffee Trees

Technological innovations tend to shorten the delay required to reach maximum productivity and to increase the yield generally. As these innovations are implemented and new trees are planted, the oldest trees rapidly become a burden as their cost per yield becomes several times higher than the cost per yield of the new trees. Low yield trees are obsolete capacity; when prices are low, a fraction of them should be removed if the farmer wants to maximize his profit.

In the coffee industry, obsolete capacity is not rapidly removed. The cost of uprooting a tree is generally very high, as well as the cost of capital and fertilizer required to prepare the land for one of the alternative crops the farmer could produce instead. Also, frequent year-to-year wide fluctuations in both output and prices act as a deterrent to uproot excess capacity, which the farmer keeps on the assumption that it provides a safety stock of trees from which additional output could be obtained, in case prices reach high levels. In several

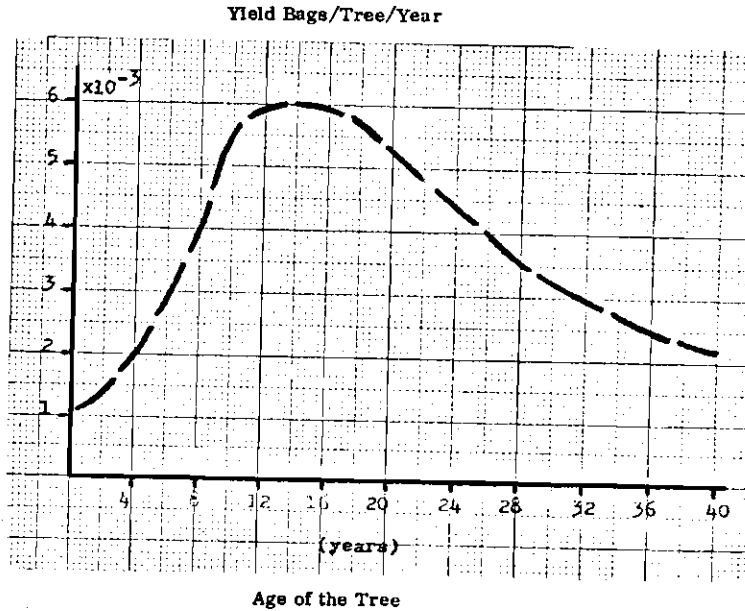


Figure II-3. Productive Cycle.

areas of the world where coffee is harvested in small family plots, coffee land is shared with other crops which account for almost 30% of the farmer's income. This farmer cannot use his family labor to uproot trees because he needs that labor to harvest the remaining trees and the other crops. During a period of depressed prices farmers have tended to abandon obsolete capacity rather than remove low yield trees. In Brazil, for instance, abandonment rates have been

as high as 50% of the total capacity during some years.

The accumulation of obsolete capacity in the world coffee industry is one of the reasons which explains why under a period with declining prices a rapid contraction of capacity and output is rarely achieved.

### 3. Government Interventions

Government interventions in the coffee industry are also responsible for the accumulation of excess and obsolete capacity. The fact that nearly 50% of the countries' foreign incomes comes from coffee exports is one of the reasons that motivates governments to maintain and enlarge coffee plantations.

As it is shown in Figure II-4, the cost and demand for imported manufactured capital goods (required to achieve sustained economic growth in the producing nations) have been rising at a much faster rate than the price and usage of coffee. While the price of an imported truck in 1960 was equivalent to 60 bags of green coffee (1 bag = 132 lb), by 1969 the equivalent price for almost the same truck was 90 bags, an increase of 50%. Other products have shown a larger price increase. A tractor costing 165 bags in 1960 cost 316 bags by 1969 and much more during the 1970s, an increase of more than 100%. Over the same period of time foreign coffee income remained constant at around the two billion dollar annually [13, p. 146].

A natural reaction to the above situation has been to enlarge the coffee plantations, to upgrade the yields per tree and to increase output to fund a large portion of the producer's industrial growth. It is understandable, then, that governments create special incentives to regulate the productive capacity of the

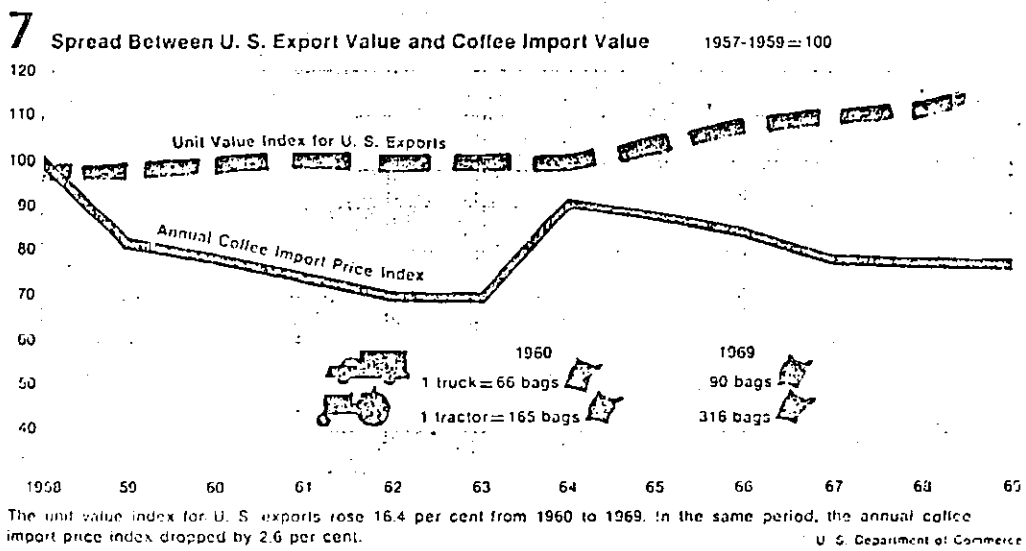


Figure II-4. Spread Between U.S. Export Value and Coffee Import Value.

farmer and at the same time fail to provide incentives for upgrading or reclamation.

#### 4. Coffee: A Labor Intensive Crop

Coffee growing requires extensive use of human labor. It is also relatively easy to cultivate and can be harvested with lower operating costs than most other alternative crops. Since substitutive crops to provide foreign earnings normally require higher capital investments and use less labor per hectare, export diversification programs turn out to be difficult and costly to implement. Labor is the major obstacle, as governments will have to find ways to use the displaced labor. Consequently, while entry into coffee activity during periods of high prices is attractive, switching to other activities under adverse price periods is very difficult. Therefore, capacity in the coffee industry tends to accumulate when prices rise, but can not be reduced in the same proportion when prices fall.

### C. Early Stabilization Efforts

#### 1. Valorization and Liquidation Policies

Attempts to control world coffee prices have existed at least since 1907 when Brazil, with 80% of the total world output, established the so-called valorization scheme. This was a scheme to regulate the flow of coffee to the market at one preestablished rate estimated to stabilize the price at a desired level. During periods of abundant crops, a substantial portion of the output was kept off the market to maintain a nationally-owned buffer stock from which exports were to be released when there was a short crop.

The above strategy implied, of course, increasing government controls of the country's distribution channels, and Brazil financed the construction of

several warehouses and offered price incentives and cash credits to farmers who sold their product to the government. The effects of the valorization policy on price stability are not clear. Rowe [24, p. 124-129] indicated that the price increase over the period was more the result of a genuine tendency for supplies at the source to fall short of an increasing demand than due to the valorization program itself.

Valorization operated until 1930, when the economic crisis of that year and the low demand broke the effective control of the coffee regulatory scheme. During this and the following years, the total world coffee output was unusually high and stocks continued to increase. Brazil could neither finance the additional storage required nor buy enough coffee to maintain the price, with the result that prices fell from 24¢ at the end of 1929 to only 9¢ per pound during 1931. These developments marked the end of the valorization scheme.

The depressed world economy during the thirties excluded the possibility of reestablishing the valorization program. In 1932 Brazil initiated a liquidation policy to remove most of its obsolete capacity. This program offered limited benefit due to the lack of funds to finance a rapid and substantial capacity reduction, and also due to the long years which it would take to see an effective reduction in output.

## 2. Post-World-War-II Stabilization Efforts: The International Coffee Agreements (ICAs)

Although the liquidation program has helped to initiate a curbing for the increasing output, the world economic recovery created a period of abnormally

increasing output, the world economic recovery created a period of abnormally high demand for coffee. World stocks were rapidly depleted and prices quoted at high levels, near 55¢ a pound by the end of 1949. The price recovery brought an end to the Brazilian efforts to reduce capacity and stimulated new planting in several other areas, mostly in Africa. Although prices continued to increase up to 90¢ a pound in 1954 (due also to a severe frost in Brazil), the excess capacity accumulated during the fifties later caused a fall in prices. By 1958 prices had already been reduced to less than 50¢ a pound.

These developments created conditions to establish joint regulatory agreements among Brazil, Colombia and other Latin American countries. These countries met at Mexico City in 1957, and implemented a policy of export quotas and stock retention; Brazil and Colombia were responsible for most of the program. In 1959 France, Portugal, Britain and Belgium (on behalf of their African colonies) promised to cut exports in accordance with the Mexico agreement.

Despite these efforts the general price level continued to deteriorate. By 1962 prices had dropped to 32¢ a pound, while little or nothing was done to reduce obsolete capacity. This was the situation when the United Nations Coffee Conference met in July 1962 with the assistance of 36 exporting countries and 22 consuming nations, including the United States. These nations signed a new International Coffee Agreement (ICA) for a period of five years, after which period a new conference would be called.

Rowe [24, p. 187] has briefly summarized the main aims of the agreement

in the following way:

1. To ensure by a comprehensive and centralized control of exports, backed up by supervision and regulation of imports, that the general level of coffee prices does not decline below the level of 1962, and that real export earnings should progressively increase.
2. To promote the consumption of coffee (importing members to have no financial obligations), and to work for the removal of obstacles to consumption (e.g. import tariffs, quotas etc.).
3. To adjust production to demand within the lifetime of the agreement.
4. To establish a policy 'relative to' stocks, which producing members 'shall endeavor by all means within their power to implement'. . . .

See also Geer [13, p. 190-310].

To achieve these goals, the agreement established a quota mechanism to regulate the members' exports and effectively limited the exports from non-member nations by providing for certificates of origin to be honored by consuming members.

Six years later, during 1968, the same countries met again to sign and review the 1962 agreement. Fundamental aspects were essentially preserved, but the new regulations established a mechanism to maintain selective margins among the different types of coffee.<sup>2)</sup> This new agreement was in operation until September of 1973. At that time, producers and consumer nations failed to reach a compromise on the price policy of the International Coffee Agreement. Hence, producers formed separate groups and the larger producers adopted a new scheme to withhold coffee from the world market. By November of 1975

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<sup>2)</sup> Geer [13, Chapter IV] claimed that enforcement of selective margins has a positive effect on short-term price stability.



a new 6-year agreement was signed, similar to the previous ones, with the participation of most of the producer nations and the backing of the United States.

#### D. The ICAs and the Stability of World Coffee Prices

The effectiveness of the ICAs is a subject of current controversy in the world coffee market. Many authors regard the system of export quotas and the companion price regulations as an effective way to reduce short-term price fluctuations [24], [25], [13]. Other authors claim that the operation of ICAs has maintained artificial prices above the price level which would result had prices been allowed to float free in the market [24], [28]. This thesis presents evidence that a system of export quotas conditioned to world price developments does not stabilize the long run cycles exhibited by the World Coffee Market. (See Chapter IX on World Coffee Policy.) The research postulates that the International Coffee Agreement per se, is a consequence of a coffee cycle of about six years, a cycle originated by the Trade and Distribution sector of the World Coffee System (See Chapter VI). Furthermore, the fact that ICAs tend to be signed by producers when prices fall, and tend to gain consumers' support five or six years later when prices rise, provides a good reason to explain the recurrent signature of ICAs at intervals of about five or six years.

Similarly, this thesis shows that the World Coffee system has the tendency to accumulate excess (obsolete) capacity every 32 years.<sup>3</sup> Systems of

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<sup>3</sup>) In fact, Chapters IV and V describe a major cycle of about 32 years, intertwined with minor cycles of about 16 and 8 years respectively. All of these cycles originate in the World Coffee Production Sector of the model used in this research.

export quotas like those in the ICAs do not have the proper mechanisms to control and reduce the accumulated coffee acreage. Even if these types of controls had been functioning over a substantial period of years, the world coffee market would have exhibited its characteristic long-run unstable performance. This is shown in Chapter IX of this research.

## CHAPTER III

### RESEARCH METHODOLOGY

This research studies the world coffee economy within the context of feedback dynamics (Forrester [57]), an area of control theory specifically designed to study large-scale dynamical systems. The chapter contains three major sections. The first one reviews two studies on the dynamics of commodity behavior; the second section explains the reasons to build a dynamic model of the world coffee economy, and the third briefly describes the methodological process followed in this research.

#### A. Previous Research on Commodity Feedback Dynamics

Two major studies on agricultural commodity behavior have previously used Feedback Dynamics concepts. One, "The Dynamics of the World Cocoa Market" by F. H. Weymar presents a conceptual feedback structure to describe the operation of the distribution and trade sectors of the cocoa industry, and then applies several econometric procedures to develop certain relations between inventory performance and price. The other study, "The Dynamic Commodity Cycle Model (DCCM)" by D. C. Meadows describes a generic model for the performance of producers and consumers within a competitive market. The DCCM has been generally accepted as a more complete and basic model than the well-known cobweb model. This section shortly reviews these two important pieces

of commodity research.<sup>1)</sup>

Weymar [45] has extended previous developments by Working [46], Cootner [38], Brennan [36], and others, on commodity price theory, and has presented evidence that both short- and medium-term price movements are related to changes in inventories. Weymar's model represents behavior as generated by the interplay of several feedback structures that link inventories, stocks and expected prices with current price formation, production and consumption (Figure III-1), and purports to explain both short- and intermediate-term behavior. The model does not include Weymar's model feedback structures in the production of cocoa.

Weymar transforms the postulated feedback loops into a set of first order difference equations; then after casting the model as linear in parameters he applied well-known statistical procedures to estimate the values of the parameters involved and runs simulation studies on several properties of the behavior of the cocoa system under exogenous disturbances, such as response to a high frequency noisy pattern on consumption and the effect of a crop failure [45, p. 136].

Weymar has noted that while the static framework of classical microeconomic theory may provide rather adequate explanation to the long run behavior of some particular commodities, it does not serve as a basis to explain shorter price movements. He has indicated that direct application of the assumptions made by microeconomic theory, when coupled with the high short-term price

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<sup>1)</sup> Meadows' DCCM was originally tested on the hog and poultry industries (Meadows [43]; Jackson [43a]; and Landel [43b]).

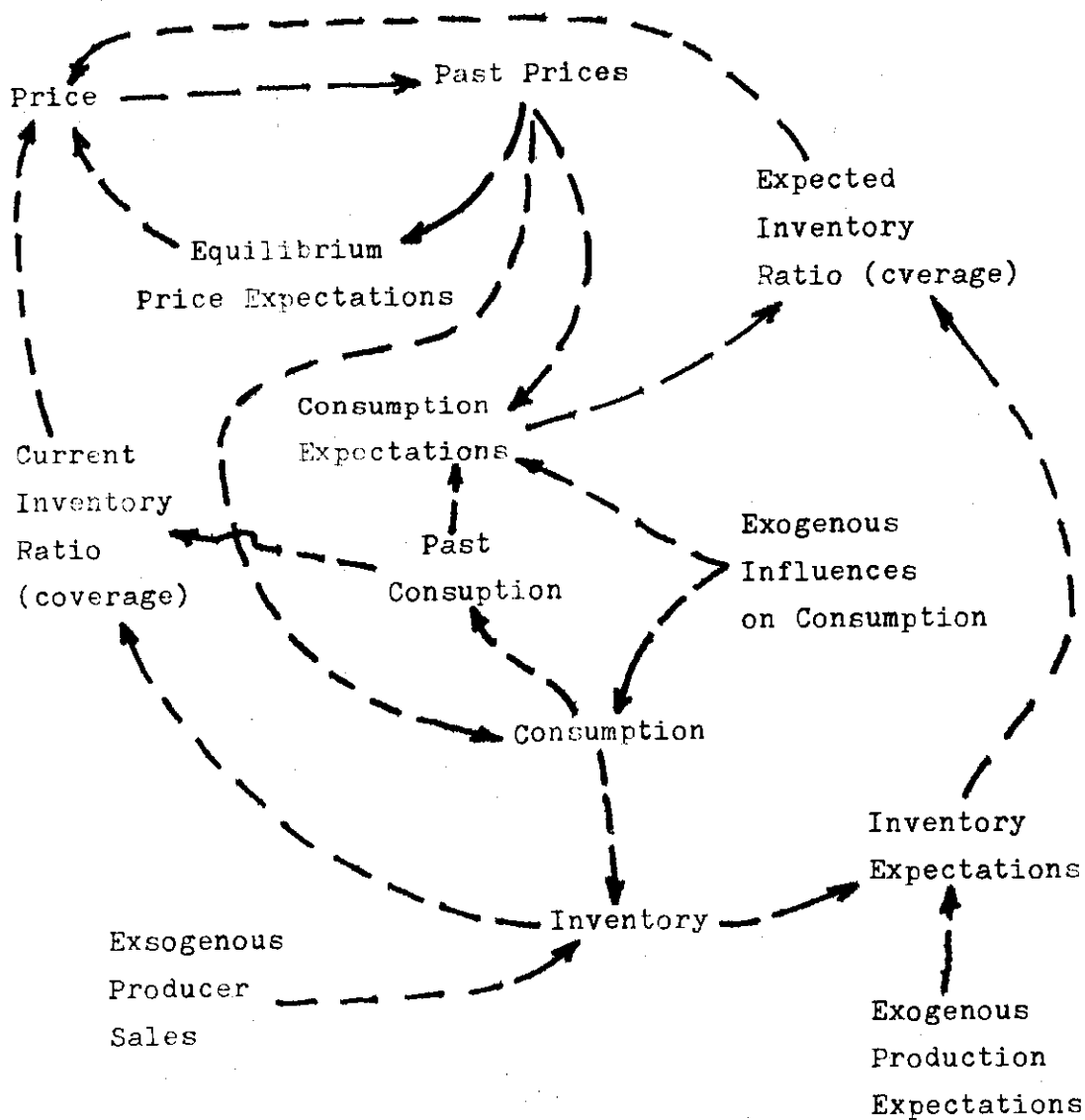


Figure III-1. Weymar's Model.

inelasticity of both supply and demand, does not drive the system toward a short-term price equilibrium. In this case, the schedules reflecting supply and demand are in theory parallel, which means that the short-term equilibrium price is either nonexistent or indeterminate. Furthermore, as the underlying assumptions of microeconomic theory overlook most intertemporal relations, the traditional cobweb model is not a good representation of the mechanics of price behavior. In particular, the cobweb model assumes instantaneous production rates and excludes the influence of expectations about the future on the current price formation. Also, the same model implies that all supply at any point in time is either consumed or wasted, and gives no consideration of the role played by stocks.

Weymar presents evidence that price expectations, price past performance and inventories are key elements to explain intermediate price movements. These concepts are related through the theory of supply of storage. This theory, grossly stated, postulates that an expected rise in prices induces traders to carry larger quantities of inventory. From this, Weymar concludes that the current price level of a commodity is a function of both a long-run equilibrium expected price and the expected future behavior of inventories. This development is central to Weymar's Commodity Price Theory [45, p. 28].

Meadows' Dynamical Commodity Cycle Model (DCCM) [43] is a generic dynamic model to explain long-range commodity behavior. Meadows [43, p. 11] shows how direct application of the cobweb model leads to several misconceptions. First the cobweb model concludes that the period of commodity cycles is twice

the length of the production delay, a result whose effect is to underestimate the actual period exhibited by most commodities. Second, the behavior generated by the model consists of similar oscillations for prices and output, except that they are reversed in phase, and the amplitude of the cycles is a function of the price elasticities of supply and demand; inventories do not play any role in determining the price pattern (a defect also indicated by Weymar). Third, the classical cobweb model is unable to generate monotonic growth or decay. This is particularly unfortunate, as a commodity may exhibit such behavior during certain periods (i.e. coffee at the beginning of its commercialization during the XIX century and natural rubber during the last fifty years).<sup>2)</sup>

DCCM consists of a simple structure containing two coupled negative-feedback loops, one to control production, the other to control consumption. Each one of these loops acts to adjust inventory coverage (months of supply) to a desired level. When the current coverage is larger than the target value, the abundant supply causes a fall in prices. In turn, the excess supply forces producers to reduce current capacity and output. On the other hand, as prices fall, consumers tend to augment the usage of the commodity, an action that tends to rise again; as prices rise producers will tend to increase capacity and output (Figure III-2). The above adjustments in both, prices and stocks do not occur instantaneously; in fact, DCCM involves several delays between action and response, a timing of events which shape behavior. In particular, DCCM

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<sup>2)</sup> The DCCM is unable to generate self-sustaining growth or decay when it is stimulated by a bounded input.

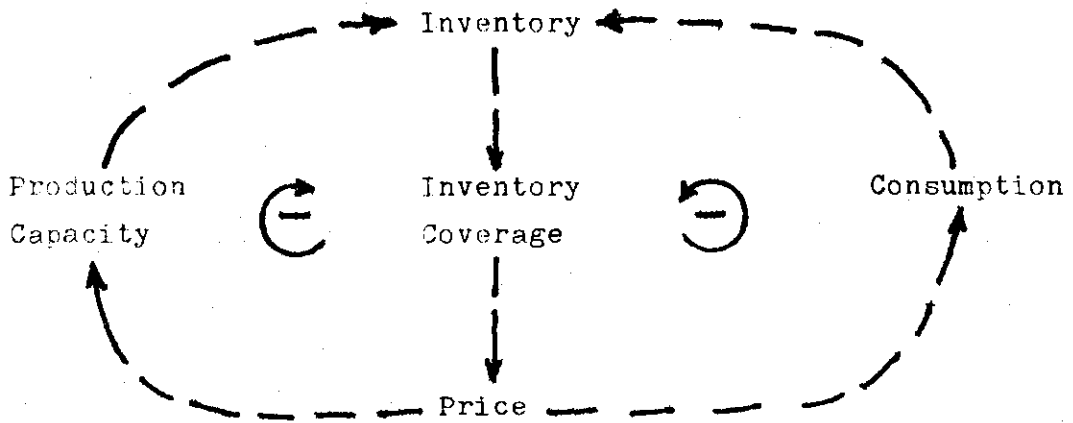


Figure III-2. Meadows' DCCM.

considers several delays which are not clearly handled by the cobweb model, and whose omission is one of the causes that makes this model underestimate the period of the cycle exhibited by most commodities [43, p. 20].

At the structural level, Meadows' model presents several innovations to explain long-run behavior. First, the rate at which capacity is allocated to produce the commodity is not only a function of the expected future price for the product, but also, of the expected price of alternative products. Meadows tested DCCM on the hog industry suggesting that the desired breeding stock (capacity) depends on the ratio between the expected price of hog and the expected price of corn (corn is an alternative product when the hog industry is depressed) [43, p. 24]. Second, Meadows' model assumes with minor modifications the inventory-price theory proposed by Weymar, and explicitly assumes price as dependent on current inventory coverage, so that higher levels of coverage lead to lower prices and vice versa. Third, the DCCM assumes that capital can be used at low or high



levels of efficiency, depending upon price trends. These facts, among others, make the DCCM far more usable and realistic than previous cobweb models. Further, and more importantly, DCCM describes qualitatively and in equation form the postulated mechanisms underlying the commodity system structure, which allows for direct policy design and testing of results. The cobweb model, on the other hand, is a descriptive model with limited normative capability.

#### B. Reasons to Build a Dynamic Model of the World Coffee System

DCCM has been partially validated on the hog, cattle and poultry industries, all domestically traded U.S. commodities.<sup>3)</sup> This research presents evidence that DCCM requires extensive redesign and increased complexity when applied to coffee, an internationally traded commodity.

The world coffee economy contains several structures and relations which do not have an equivalent counterpart in the Dynamic Cycle Commodity Model. First, world coffee prices reflect not only the level of stocks and its rate of change, but also the domestic policies followed by each one of the producer nations. Second, Meadows' DCCM model was built on the assumption of perfect competition. Thus, current stocks are always marketable stocks at the current price; this is not true for coffee, a commodity in which the larger producers are able to retain inventories and reduce current supplies to the market with the purpose of supporting prices. Third, obsolescence and abandonment of coffee

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<sup>3)</sup>Wright's thesis on Validation of Dynamic Models [58].

trees play an important causal role in coffee price behavior, as described in Chapter V of this research. DCCM does not consider directly the problem of obsolete capacity. Fourth, coffee is a labor intensive crop; when prices rise and the income to the farmers is high, additional labor is attracted to coffee zones. The increase in labor supply facilitates the expansion of coffee acreage. These considerations and several others suggest the need to redesign Meadows' DCCM and build a more complete model for the coffee industry.

The World Coffee Model proposed in this thesis is able to replicate both long-run cyclic behavior and intermediate movements. Weymar's dynamic model for the world cocoa business replicates intermediate-range cyclic behavior. Although Weymar has expanded the theory of Supply of Storage to capture certain effects provided by the cocoa future market [45, p. 39], the structural feedback loops of his model do not include feedback loops arising from interplay of hedgers and speculators (Figure III-1). The World Coffee Model postulated here extends Weymar's model and specifically describes structures to describe the functioning of the future coffee market. As shown in Chapter VI of this research, the behavior of traders in the future market (the "commodity exchange") has an effect on the intermediate-range coffee cycles of about six years of duration.

### C. Methodology to Study the Behavior of the World Coffee System

The purpose of this research is to study the behavioral characteristics of the long-and intermediate-cyclic movements generated by the World Coffee

System. In particular, this study intends to establish the conditions under which stability could be attained.

Behavior in a dynamical system results from the interaction between exogenous inputs and system structure [57], [58]. This research takes the view that system structure is composed of coupled information feedback loops. An information feedback loop is a closed chain of causes and effects, each of which is decoupled from the others in time, so that any effect appears later than its cause (Forrester [57, p. 61]).

Control theory is the area of knowledge that studies information feedback structures. Traditionally, mathematical control theory has been successfully used in studying the behavior of man-made systems, most of which are, by design, linear, stable and time invariant. Only a few cases of nonlinear systems can be cast within the classical procedures offered by this theory. Feedback Dynamics [57], on the other hand, is an area of control theory specifically created to analyze the more complex, time-variant and non-linear socio-economic systems.

The methodology of Feedback Dynamics has been described by Forrester [57] as follows:

1. Identify a problem
2. Isolate the factors that appear to interact to create the observed symptoms
3. Trace the cause-and-effect informations-feedback loops that link decisions to action to resulting information changes and to new decisions
4. Formulate acceptable formal decision policies that describe how decisions result from the available information streams
5. Construct a mathematical model of the decision policies, information sources, and interactions of the system components

6. Generate the behavior through time of the system as described by the model (usually with a digital computer to execute the lengthy calculations)
7. Compare results against all pertinent available knowledge about the actual system
8. Revise the model until it is acceptable as a representation of the actual system
9. Redesign, within the model, the organizational relationships and policies which can be altered in the actual system to find the changes which improve system behavior
10. Alter the real system in the directions that model experimentation has shown will lead to improved performance

The above methodological process can be grouped into three main steps.

- 1) Descriptive phase. The descriptive or model-building phase consists of postulating a set of information feedback loops to explain the behavior of the system. Then the feedback loops are translated into a dynamic mathematical model.<sup>4)</sup>
- 2) Behavior reproduction phase. This involves the simulation throughout time of the postulated model, a process which is accomplished on a large scale computer. A condition to postulate a model as a possible representation of the real system requires that the model be able to replicate its relevant behavioral characteristics. Behavioral characteristics refer here to type of cyclic movements, period and amplitude of the wave(s); phase between related variables, and stability.
- 3) Prescriptive phase. This step involves the design of alternative corrective policies to improve the system performance. This usually involves either the addition to or omission from the model of information feedback loops.

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<sup>4)</sup> The mathematical counterpart of a feedback loop is a set of first-order difference equations (Wright [58]).

The process of building a model, simulating behavior and improving performance is a feedback structure in itself (Figure III-3). Initially, the behavior of the real system is analyzed, both qualitatively and quantitatively. Qualitative analysis involves the construction of a verbal description of the system's performance. A set of feedback loops is then built to describe the formation of the behavioral patterns observed. These loops represent a hypothesis to be tested. The statements in each loop are translated into mathematical equations and a simulated time trajectory is calculated. Then the trajectory is compared with the real system performance to discover defects in postulated feedback loops, in the mathematical model, or in the methodology used to analyze the system's behavior.

Validation is the process of assessing, at each iteration, how credible the postulated model is with respect to the actual system. It encompasses several steps, each of which occurs inside the methodological feedback process presented in Figure III-3 [58, p. 53]. The first step is to assess the credibility of the results obtained from the analysis of the data (Loop V-1, Figure III-3). The second step is to construct feedback loops which best describe the generation of the analyzed behavior (Loop V-2, Figure III-3). Third is the verification that each one of the proposed equations in the mathematical model reflects what it is described by the feedback loops (Loop V3, Fig. III-3). The final step consists of assessing how well the simulated behavior compares with the observed behavior and to what extent additional feedback iterations should be followed so that the behavior rendered by the model exhibits the basic characteristics

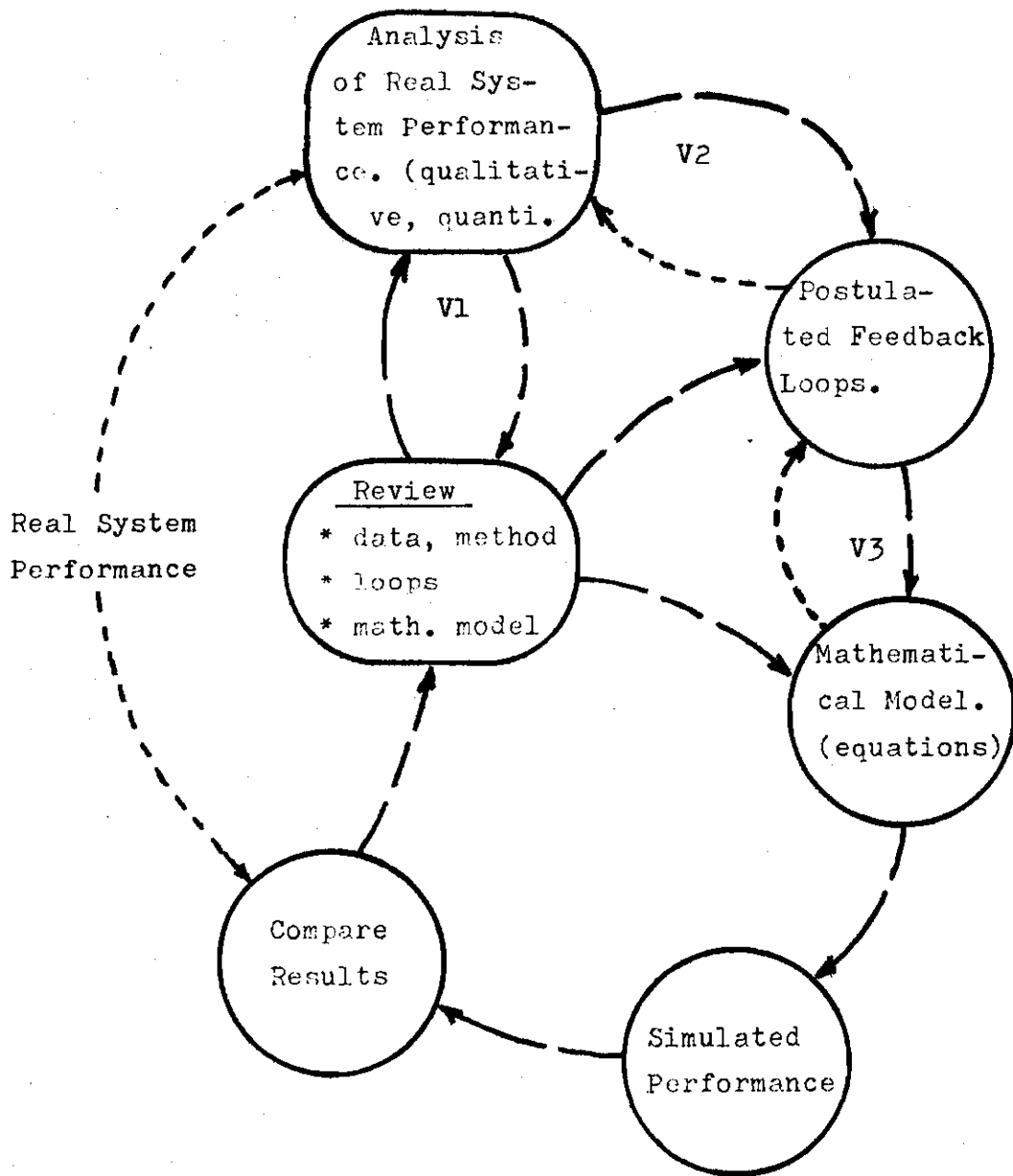


Figure III-3. Methodological Feedback Process.

observed in the performance of the real system. The research reported here is the result of repeating the above feedback process over a period of two years.

This thesis presents a useful device to build a feedback structure. It consists of breaking the cyclic patterns of behavior exhibited by the system into their basic cyclic movements, via a Fourier type of analysis, i.e., spectral analysis; each one of these basic movements appears as a combination of a fundamental cycle and several harmonic cycles of shorter duration. The modeler's task is to build separate feedback loops whose function replicates each one of the fundamental movements and each one of the harmonics. This process insures to a large extent, that the postulated model contains feedback structures whose operation causes a composite cyclic behavior close enough (in shape) to the observed pattern.

In particular, Chapter IV, of this thesis, decomposes the cyclic performance exhibited by the world coffee industry into its basic cyclic movements and harmonics. In turn, Chapters V and VI postulate specific feedback structures whose operation causes the appearance of each basic movement and several of the harmonics. Chapter VII presents the overall model behavior and Chapter VIII compares the simulated performance of the model postulated in this research with the actual behavior of the coffee system.

A convenient way to simulate the behavior produced by a model is to disturb the system when all variables are at rest, i.e. steady state condition. The exogenous disturbance is called the input to the system. In the dynamic coffee model postulated in this study world coffee consumption per year is an

input to the model. In other words, internally generated changes in the model variables do not affect consumption of coffee.

An input can take several forms; it could be exponential with growth, or an instantaneous impulse or the frequently used step function. The use of a step input to disturb a dynamic model generally permits one to visualize with more clarity the behavior generated by the system (Forrester, [57, p. 38]). In particular, the step input is a useful device to analyze the stability of the system.<sup>5)</sup> The exponential input, on the other hand, has the benefit of testing the range of operations of the model variables, and allows direct comparison of the actual performance of the coffee industry with the model behavior. The dynamic coffee model postulated in this research has been tested with these two types of inputs. The model has been initialized at steady state, with variables roughly resembling the conditions of the world coffee economy at the turn of the previous century.

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<sup>5)</sup> Standard texts in control theory define a system as stable if a bounded input produces bounded behavior.



## CHAPTER IV

### QUANTITATIVE ANALYSIS OF THE WORLD COFFEE

#### CYCLIC MOVEMENTS

The violent fluctuations of world coffee prices and income represents a problem of great concern to coffee farmers, traders and governments. This chapter presents evidence that the fluctuations displayed by the coffee economy can be described as a combination of several cyclic movements with periods ranging from 2 to 32 years, and also that the long-term oscillations are wider than the high frequency or short-term cycles.

#### A. Observed Cycles

Visual inspection of the pattern of the last two centuries of coffee prices and output shows a marked unstability and suggests the possibility of cyclic movements of varying period and amplitude. The behavior exhibited in Figures IV-1 and IV-2 may reveal to the reader a major movement with duration of some 20, 30, or 40 years, intertwined with a group of minor movements whose period could be as low as 2 years, or as high as 7, 8, or 10 years. Clearly a visual inspection of the world coffee patterns, with no consideration of the role played by harmonic movements, does not constitute a sufficient basis for informed statements about this complex cyclic behavior. Many observers have been misled into misinterpretations and incorrect conclusions. The following remarks,

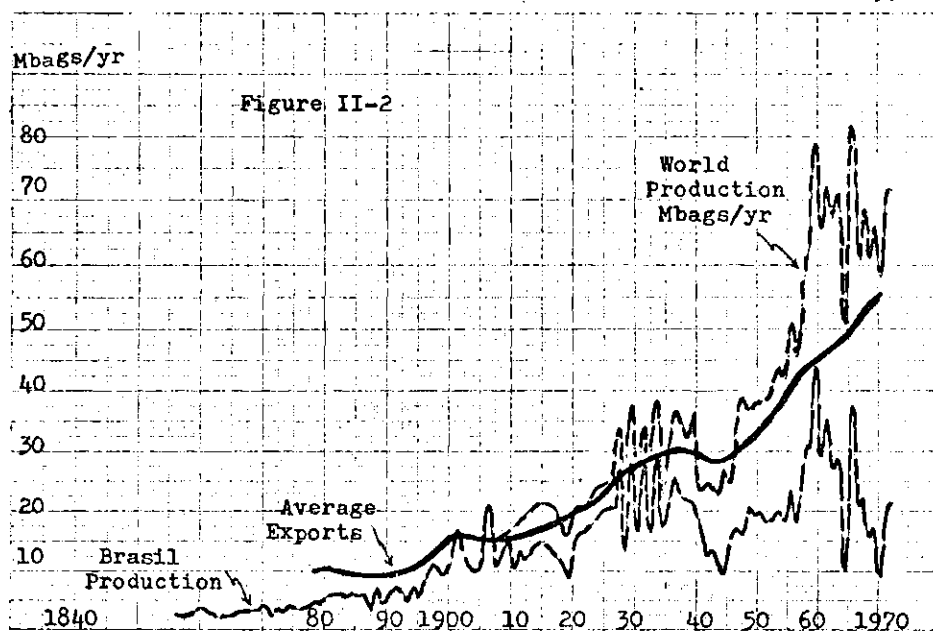
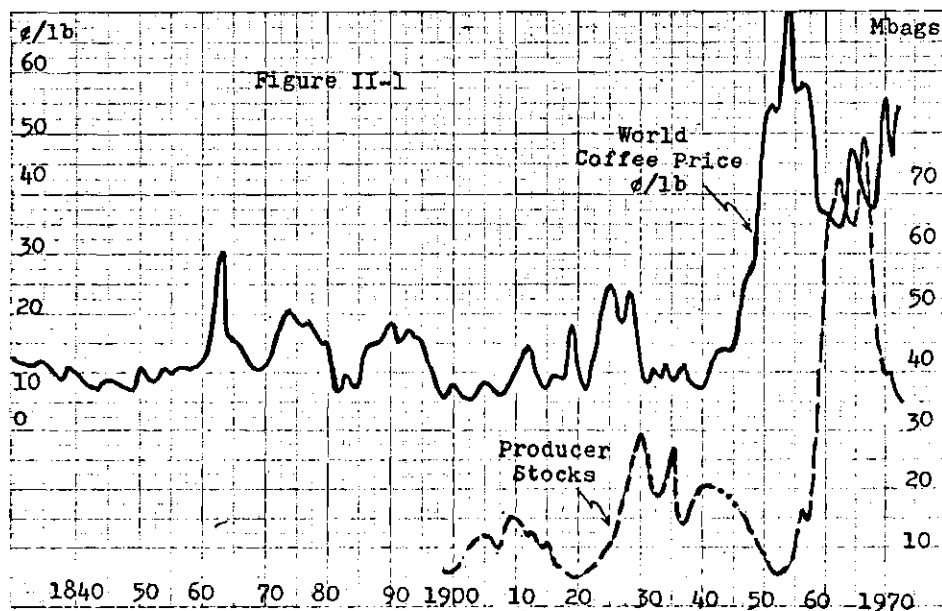


Figure IV-1, IV-2. World Coffee Behavior.

taken from several scholars and coffee policy administrators, provide the reader with background to appreciate the lack of agreement in this matter.

...Decade after decade was marked by overproduction and underproduction, with a wavering balance maintained during a few intermediate years.

The cycle runs full course about every seven years. . . .

A. Uribe, *Brown Gold*, p. 134, 1954.

Dr. Uribe has been a coffee farmer and has held a long association with the Federación Nacional de Cafeteros in Colombia.

...Fluctuations of the world coffee crop are due mainly to: (i) damage to the coffee trees by the weather; (ii) the coffee tree two-year cycle; (iii) faulty techniques of coffee production; (iv) the coffee-tree productive cycle; (v) the socio-economic conditions of coffee culture; and (vi) the structure of production costs.

Equilibrium has been the exception rather than the rule of the world coffee economy. Between 1790 and 1956, a span of 166 years, overproduction prevailed in six periods adding to 53 years, and underproduction in five totaling 36 years.

J. Ruiz-Lara, *Fluctuations of World Coffee Prices: An Economic Analysis*.  
Ph.D. thesis, Graduate College of the  
University of Illinois, Urbana, p. 2, 1961.

Dr. Ruiz was head of Planeación Nacional, planning agency of the Colombian government from 1966 to 1970.

...(the coffee cycle) represents a long-term cobweb cycle, covering sometimes a span of two decades. Intertwined with this long cycle are purely short-run fluctuations, which are another source of disturbance.

U.N., *The Problem of Stabilization of Prices of Primary Products*, p. 21, 1969.

...A further form of research has been to establish the coffee price movements since 1950 as a price cycle that revealed the typical feature of a cobweb cycle with a time lag of some six to eight years.

T. Geer, *An Oligopoly: The World Coffee Economy*, p. 43, 1971.

...The variation of production with time suggests a two-year cycle. Nevertheless, statistical analysis of the time series shows that the cycle is only an apparent one and that production behaves randomly. On the other hand the analysis does leave open the possibility of a twelve-year cycle for Brazilian production...

*Perpectivas del Café a Corto Plazo*, anonymous article published in Coyuntura Económica, Bogotá, 1972. Translation by Donovan Young.

...there is the tendency for periods of generally high prices to alternate with ones of generally low prices, a complete cycle lasting about 20 years....Whether such movements can be described as a true cycle, endogenous to the coffee production-consumption system, is not the subject of this paper, although it is indeed an interesting question. All that needs to be noted is that in the past, major movements have tended to repeat themselves at time intervals within the range of 13 to 40 years.

A. H. Gelb, *Coffee Prices and the Brazilian Exchange Rate*, *Oxford Economic Review*, 1971.

...On the basis of the observations, consequently, there are reasons to believe the existence of an oscillatory behavior of the series of coffee prices in the period 1856-57 to 1904-05....

The preliminary analysis of the series of coffee prices during the past century shows that the behavior of the coffee market was altered after 1900. In the second half of the past century, there are some cycles, which will be explained subsequently, with an expanding phase of six or seven years and declining phases of longer duration. Since the beginning of this century, however, this behavior is more hidden....

A. Delfim Netto, paper published in "Essays on Coffee and Economic Development," Instituto Brasileiro do Café, Rio de Janeiro, 1973.

Delfim Netto was Minister of Finance of Brazil from 1967 to 1974.

The above quotations speak for themselves. The lack of a precise statement about the number, duration in years, and relevance of each one of the cycles involved in the coffee industry, together with varied explanations to describe how each one of those cycles is generated, presents a great obstacle to formulation of effective stabilization policies. Furthermore, the almost invariant attachment of 'cobweb type' explanations to these cycles<sup>1)</sup> compounds to create even more confusion as there are too many cycles to fit just one description of the model causing their appearance.

On the other hand, the above quotations, when jointly considered, describe cycles of roughly 20, 14, 8 and 2 years. These are cycles which the authors have observed on the basis of statistical analysis of data, collected during different periods, or perhaps more importantly from the author's own expertise and continuous contact with the coffee industry. One can hardly dismiss or neglect what these authors have postulated. Therefore, a more promising line of thought can be established by assuming that the world coffee patterns contain, tentatively, the full sequence of cycles claimed by the sources, and then proceed to explore the correctness and nature of each cycle.

#### B. Procedure to Establish Cyclic Behavior

Several techniques can be used to estimate cyclic movements in a time series. These procedures vary from the widely used moving average technique

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<sup>1)</sup> Coffee literature invariably presents the biological cycle of the coffee tree as having a duration of two years.

to more sophisticated statistical methods such as parametric modeling or spectral analysis.

Moving average, although crude, is useful, especially when used as a complement to more advanced procedures. A disadvantage is that it filters out high-frequency cycles, giving an estimate for long-term but not short-term movements.<sup>2)</sup>

Netto [21] has used classical non-parametric tests to search for trend and oscillations in the world coffee price series from 1850 to 1950. His analysis shows no reason to reject random price oscillations around a constant mean; the analysis rejected the presence of a secular trend.<sup>3)</sup>

Our objectives in analyzing the behavioral patterns of the world coffee economy are: (i) to establish the existence of non-random cyclic behavior; (ii) to estimate the period of each basic cyclic movement; and, (iii) to find the dominant cycles, and hence, differentiate among several possible fundamental movements and their harmonics of higher frequency.<sup>4)</sup> Using these objectives

<sup>2)</sup> The moving average or equivalently the exponential smoothing are special types of linear filters. The use of filters in time series analysis to 'clean' the data is a subject of current disagreement in the field of statistics. One obvious disadvantage is that filters tend to add autocorrelation to the time series. See Granger and Hatanaka [52].

<sup>3)</sup> Netto used Kendall-Mann test to reject the hypothesis of secular trend, and Wallis and Hoone test to reject the hypothesis of cyclic behavior [21, p. 43]. He found three cycles of 11, 16, and 20 years during the last half of the XIX century, and cycles of six or seven years during the present century [21, p. 48].

<sup>4)</sup> A periodic time series can be decomposed into an infinite series of sines and/or cosines by Fourier analysis, i.e. if  $f(t) = f_t(\epsilon + T)$ ,  $T$  = period in years, then for  $t$  in years

$$f(t) = A_0 + A_1 \sin \frac{2\pi t}{T} + \sum_{j=2}^{\infty} A_j \sin\left(\frac{2j\pi t}{T} + \phi_j\right).$$

(continued on next page)

in the analysis of data insures that the model to be constructed includes feedback structures that generate the fundamental frequencies of the behavioral pattern.

Power spectral analysis is the statistical technique best suited to achieve the proposed objectives. Basically, the spectral technique provides an estimation of the variance (power) of the time series at each frequency band. Thus, the procedure classifies movements by period and by relative importance in shaping the series. Furthermore, the spectral plot of a time series has well defined statistical properties, a fact which provides the capability to test hypothesis about cyclic characteristics.<sup>5)</sup>

So far the techniques of spectral analysis have received little attention in econometric research on coffee. However, it is perhaps the best way of preventing confusion about the definition and relevance of trends, long-run cycles and short-term movements in a behavioral pattern. To my knowledge, only Gelb [ibid] has previously used spectral analysis within the context of the coffee economy. He has studied the relatedness at several frequencies between the world price and the Brazilian exchange rate. Among several other things, Gelb found a high degree of relatedness between these two variables at periodicities of around 20 years, but no relevant association between the variables at higher frequencies.

The next sections describe the time series used and the cyclic movements rendered by spectral analysis techniques.

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The argument of the second term is called the fundamental frequency while the other terms are higher frequency harmonics. Choice of the fundamental period  $T$  is arbitrary as long as  $T$  is as long as the longest real period.

<sup>5)</sup> The reader not familiar with spectral analysis may find a brief summary of the procedure in Appendix C.

### C. Data and Time Series Used

Power spectral plots have been constructed for both the annual world coffee prices and output, over a long time span (1825-1973) to provide adequate spectral plots estimated with relatively small variance. Appendix D shows the sources of information used.

The pattern of prices during the period appears in Figure IV-1. Prices fluctuate around the 12¢/lb mark, up to 1946, the year after which prices exhibit a wide jump toward and around 45¢/lb.<sup>6)</sup> Since spectral theory presupposes stationary time series, i.e., constant mean and variance, the series has been adjusted for mean and variance in order to obtain a transformed stationary series over the period 1825 to 1973. Power spectral plots have been developed for the following price series:

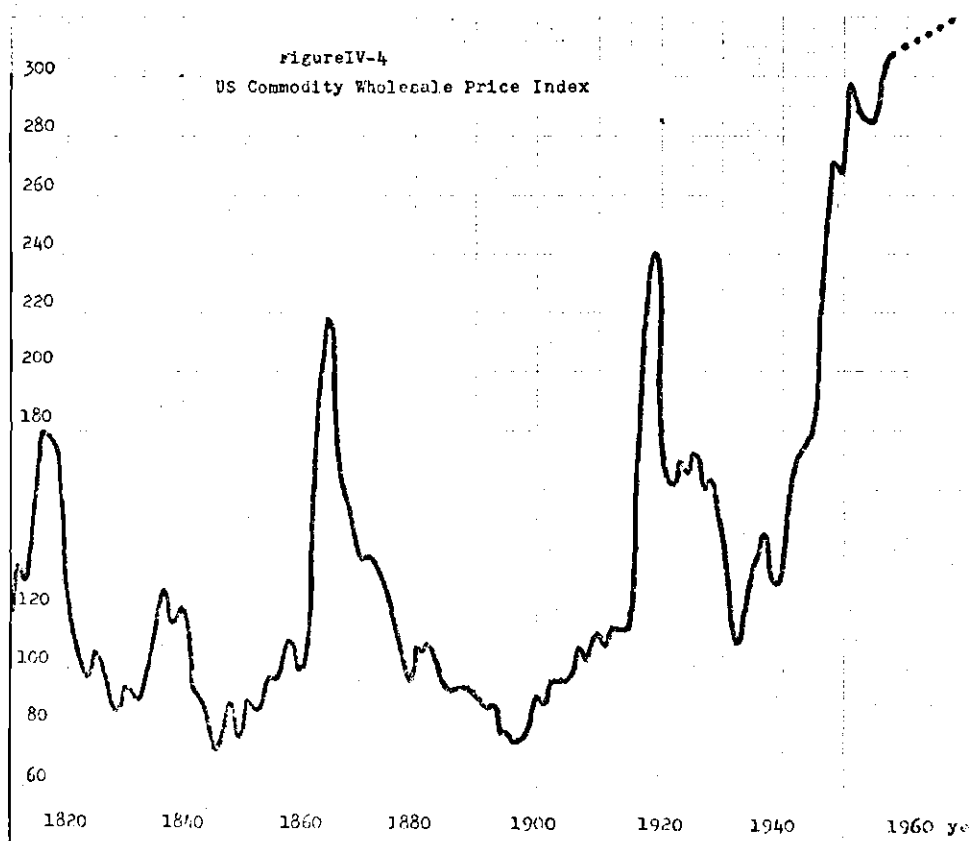
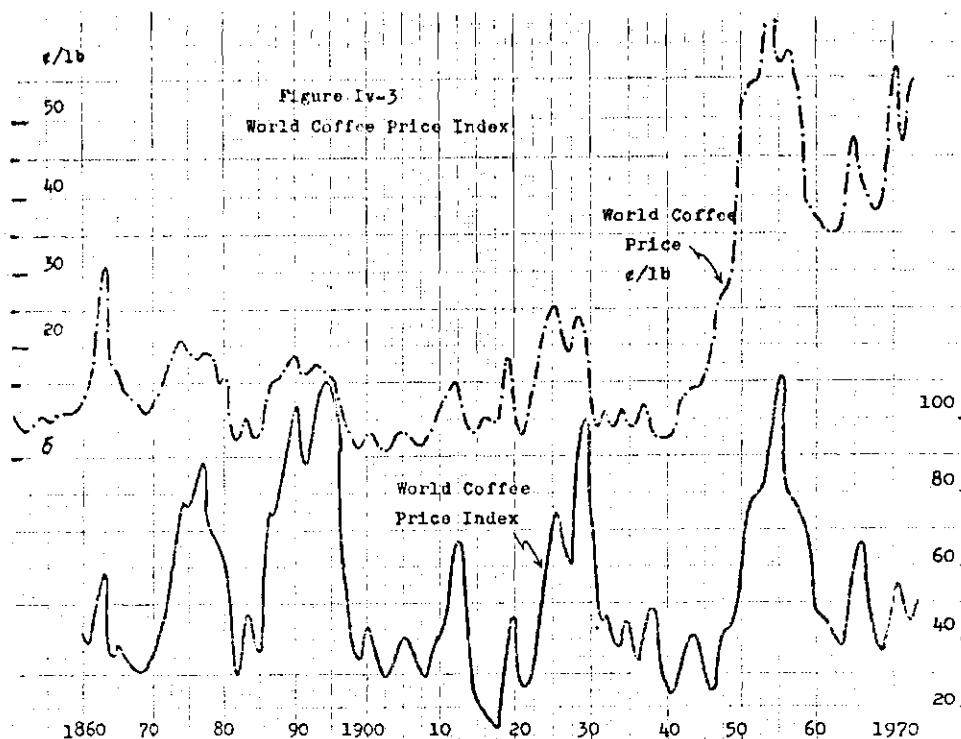
- a. Annual world prices (in \$ of 1900), 1825 to 1976
- b. Annual world prices and series adjusted for mean and variance,  
1825 to 1973
- c. Quarterly adjusted prices, 1896 to 1973
- d. Relative world coffee price index, 1861 to 1973.

Relative world coffee price index (Fig. IV-3 and IV-4) has been calculated by

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<sup>6)</sup> Worldwide commodity price inflation has been taken as the main cause of this increase in coffee prices. Forbes, March 1, 1975, in "Is Depression the Only Cure for Inflation" shows a chart exhibiting the estimated world consumer price index since the middle ages to modern times. The index is fairly stationary, except during two remarkable periods, when the index showed abnormal growth. The first of these occurred toward the second half of the XV Century when the index rose from 100 to 600; the second, right after 1945, when the index rose from 600 to 4000.





Figures IV-3 & IV-4. Price Indices.

dividing the raw coffee price at year  $t$  by the wholesale commodity U.S. price at year  $t + 1$ . This series provides a useful device to check for possible exogenous cycles. If this and the other series exhibit similar periodic movements, there is a reason to believe that all these movements are internally generated by the world coffee system.

Figure IV-2 shows the production patterns of Brazil and the rest of the producer countries. In general, cyclic behavior of these two series exhibit remarkable similarities, although world production seems to fluctuate around an exponential line, while Brazilian output appears to be leveling off around 20 million bags per year (MB/yr). However, even at today's reduced Brazilian market share of about 35% (from a 70% during the early nineteenth century), most authors regard Brazilian output as the major contributor to price developments.<sup>7)</sup> On the other hand, a research conducted on the sources of information in Appendix D, provided reliable annual world output figures only for the period 1915-1973, and 58 pieces of data are definitively not enough to develop even a very rough spectral plot to capture a long-term cycle. For these reasons we have prepared spectral plots from the Brazilian production series for the period 1856-1973.

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<sup>7)</sup> A study by Fedesarrollo [10, p. 144] claims that 77% of the total variation in world output during the last 20 years can be explained by Brazil output fluctuations.

## D. Behavior of World Coffee Prices and Output

### 1. Behavior of Prices

The spectral plots obtained from the 'corrected' and 'uncorrected' series, reflect salient similarities at roughly similar frequency bands.<sup>8)</sup>

Figure IV-5 displays the power spectra given by the annual prices from 1825 to 1946, years during which the series did not exhibit trend. The solid line on the same diagram represents the spectra of the same series, extended up to 1972, with the post war price jump removed and adjusted to provide a fairly stationary series. Figure IV-6 shows the spectral plots obtained on the relative price index, calculated as explained before.

These plots exhibit very similar spectra with respect to shape, power distribution and peaks. In fact, the F statistic to test the null hypothesis that the two plots on Figure IV-5 are equivalent becomes significant at a value greater than 5%. Thus, on the basis of the data used, one cannot claim with 95% confidence that the two spectra are different. This lack of statistical result and the visual evidence suggest that the plots contain the same distribution of variance at each frequency band. Therefore, the adjustment of the post-war jump has not apparently introduced spurious information into the frequencies involved in the coffee price pattern, and more importantly, the cyclic movements observed during the post war period are of the same type as those generated up to 1946.

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<sup>8)</sup> The ordinate in the spectral plots measures the power at each frequency. The area under the plot covered by a frequency band estimates the portion of the total variance of the time series which is produced by the frequencies embodied within the band.

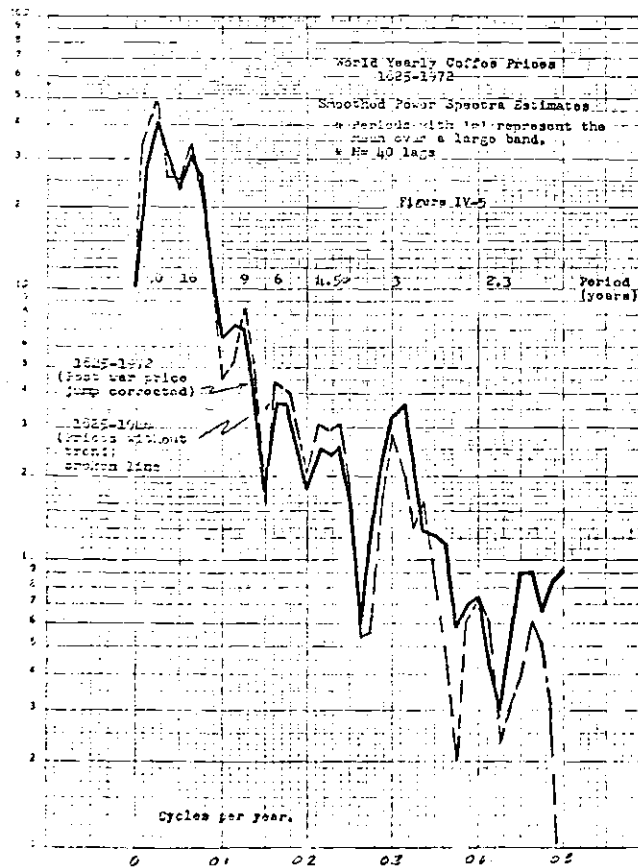


Figure IV-5. Spectral Plot of World Coffee Prices.

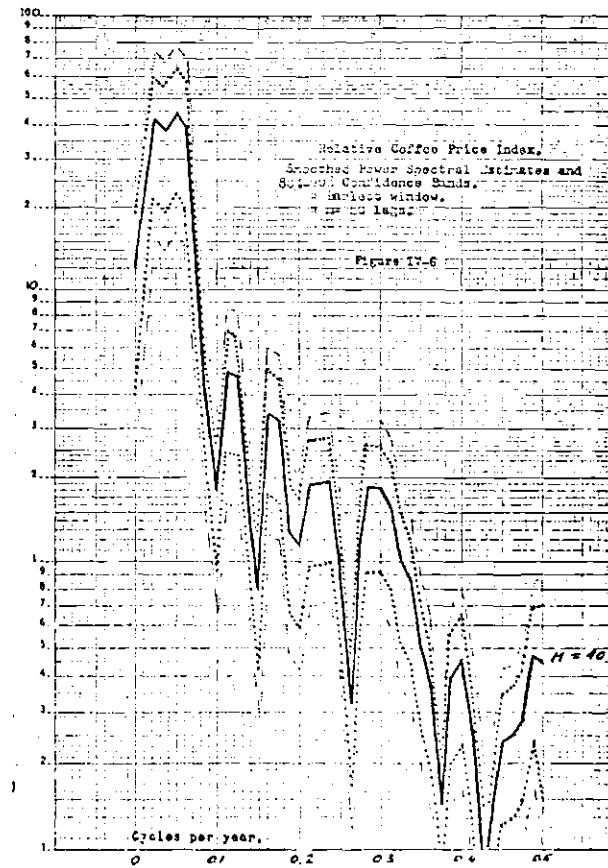


Figure IV-6. Spectral Plot of Relative Coffee Prices.

Similarly, the F statistic shows at about 90% confidence, that the spectrum rendered by the relative coffee price index is equivalent to the one obtained from the annual price series.

Each peak in a spectral plot of a time series may indicate the presence of a cyclic movement whose frequency is the frequency under which the peak appears. To establish the presence of a cyclic movement with some confidence level, confidence bands have been drawn at each side of the observed spectral plot, as shown in Figure IV-6. If it is possible to draw a smooth curve between the confidence bands, a curve which does not peak anywhere, one would not reject the null hypothesis of no peak, i.e., the hypothesis that no cycle is present in the plot. At a very low confidence level, the two bands around the plot will tend to be much closer to it, which makes it easy to reject that most peaks observed are not cyclic movements. On the other hand, at a very high confidence level, the two bands would be wide, and to draw a continuous line with no peaks in it would suffice to neglect all peaks, and claim that the time series does not contain any cyclic movements.

Figure IV-6 shows 80% and 90% confidence bands drawn around the spectral plot rendered by the relative coffee price index series. At 90%, there is only one chance in ten that a peak on the 0.3 cycles band (3.3 years of period) is a spurious peak. At 80%, there is one chance in five that two peaks at 0.035 and 0.16 cycles per year (cpy) are spurious. The 0.035 cpy is a low frequency movement whose period may be as low as 16 years or as high as 40. To be sure, this cyclic movement could be really formed by a combination of several frequencies embodied within the 0.035 band, as suggested by the wide band covered by the peak on the

spectral plot. Those cycles, of roughly the same power, combine to generate a sizeable portion of the total variance exhibited by the series. The second prominent peak appears around the 0.16 cpy band, or about 6.25 years of period, and its power is almost ten times lower than the power exhibited by the previous movement. Furthermore, confidence bands drawn upon the spectral plots produced by the annual price series (Figure IV-5) also confirms the existence of the same cycles at roughly similar confidence bands.

When studying economic time series one very rarely finds pure sine waves with no harmonics of higher frequency.<sup>9)</sup> Therefore, if a long cycle exists in the behavioral pattern, the spectra will normally reflect the presence of its harmonics, with progressively lower power for higher frequencies than that exhibited by the fundamental frequency. Thus, even if a cycle is not well defined in the plot, the presence of higher order harmonics should be taken as additional evidence that the major cycle is indeed built in within the time series in question. To check the presence of harmonics in the annual coffee price series, all peaks in Figure IV-5 have been listed in the following table, where the first column shows the mid-point frequency around a bandwidth of 0.0125 cpy. This is the frequency interval when one wants to estimate 40 different cycles ( $\text{bandwidth} = \frac{1}{2M}$ ,  $M = 40$  lags). The second column in the table shows the approximate period of the cycle in years, together with its range of variation, and the third column presents an estimation of the power provided by each frequency band.

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<sup>9)</sup> Granger and Hatanaka [52].

Table IV-1. Peaks in Spectral Plots of the Annual World Coffee Prices

1825-1972

Cycle N <sup>0</sup>	Midpoint Frequency (+ 0.00625) cpy	Approximate Period (Years)	Range of Period (Years)	Power of Band (Area Under Band)	Chance that Peak is not Spurious
1	0.028	35.71	29.20, 45.98	0.500	80%
2	0.061	16.39	14.87, 18.26	0.375	
3	0.115	8.70	8.25, 9.19	0.100	Low
4	0.165	6.06	5.84, 6.30	0.100	80%
5	0.225	4.44	4.32, 4.57	0.067	Low
6	0.310	3.23	3.16, 3.29	0.105	90%
7	0.400	2.50	2.46, 2.54	0.009	Low
8	0.455	2.20	2.17, 2.23	0.011	Low

A simple inspection of the above table indicates the presence of higher order harmonics, whose fundamental frequency is the longest movement. This is shown in the following table, where the first three columns represent the cycle number, the midpoint frequency, and its second multiple, respectively. Within less than a 10% error, frequencies 2, 3, 5, and 8 are harmonics of frequency 1.<sup>10)</sup>

<sup>10)</sup> The error is due to lack of power resolution of the spectral analysis. No attempt was made to test the significance of this type of error.

Table IV-2. Harmonic Sequence

Cycle No.	Midpoint Frequency cpy	Second Multiple cpy	Percent Error
1	0.028	0.056	8.93
2	0.061	0.122	6.08
3	0.115	0.230	2.22
4	0.165	0.330	
5	0.225	0.450	1.11
6	0.310	0.620	
7	0.400		
8	0.455		

On the other hand, frequency No. 6 does not appear to be a harmonic of frequency No. 4, though the observed difference is well below 10%. In this case, the two frequencies have roughly the same power, and more importantly, cycle No. 4 is significant at a much wider confidence band.

Thus there is no reason to reject the existence of a low frequency movement of about 29 or more years in the world coffee price series, a claim which can be made with 80% of confidence, i.e., one chance in five that the cycle is the result of random events. Further, the presence of harmonics permits one to postulate the existence of such a long movement. Certainly, 150 years of data have not been enough to enhance the power resolution of the spectra at this low



frequency. Nevertheless, a more accurate figure for the period of years covered by this cycle could be obtained from the following observations.

First, the 8th (highest) frequency listed in Table IV-1, with a period between 2.17 and 2.23 years, appeared in all the spectral plots when the number of lags was changed to narrow the bands. (See the closing window technique in Appendix C.) With 150 data points, this frequency is accurate enough; it is also the fourth harmonic of the major fundamental frequency; therefore, the third harmonic should have a period not lower than  $2.17 \cdot 2 = 4.39$  years and no higher than  $2.23 \cdot 2 = 4.46$  years, a range which is included within the range obtained for frequency No. 5 in Table IV-1. Following the same reasoning, it is possible to find the set of ranges for the rest of the frequencies, as shown below:

Table IV-3. Probable Period of Coffee Cycles.

<u>Frequency No.</u>	<u>Revised Range (years)</u>	<u>Range Given By Spectra (years)</u>	<u>Probable Period (rounded) (years)</u>
1	34.72, 35.68	29.20, 45.98	35.0
2	17.36, 17.89	14.87, 18.26	17.5
3	8.68, 8.92	8.25, 9.19	8.8
5	4.34, 4.46	4.32, 4.57	4.5
8	2.17, 2.23	2.17, 2.23	2.2

Second, for the above observation to be true, a cycle of about two years should exist beyond any doubt. With annual prices the actual value of the period rendered by the spectral plot is likely to be biased as the two-year cycle may appear aliased with higher-order frequencies. To establish the existence of this cycle, we used quarterly coffee prices since 1895 to 1972. The spectral plot appears in Figure IV-7, and shows a small peak at a frequency of 0.123 cycles per quarter, just 2.03 years. With quarterly data, this estimator for the period in question is more reliable than the previous estimators. Furthermore, all literature searched on coffee claims the existence of a cycle of about two years, i.e., the biological cycle of the coffee tree.

With a value of 2.03 years of period for the highest harmonic, one could postulate the following periods for the other concurrent frequencies: 4.06; 8.12; 16.24; and 32.48 years, respectively.<sup>11)</sup>

Finally, direct observation of the price time series indicates a cycle of about 30 years for the major movement. With the information provided by the spectral power densities, one can attempt to rebuild the price series, and be able to 'tune' the values estimated by the spectra. Using the Fourier

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11)

The spectra of quarterly prices suggests cycles at 3.42, 2.03, 1.45, and 1.09 years. The power of the spectra at longer cycles exhibit a rampant growth up to 1000; 308 quarters of prices or 77 years is too short a period to resolve the longer movement and its harmonics. The 1.45 years of period, reflected by a well established peak at 0.172 cycles per quarter confirms the six year cycle, i.e.  $1.45 \times 4 \simeq 5.8$  years. Finally, the cycle at 1.09 years roughly corresponds to the well-known cycle associated with the seasonal building of processor inventories during the fall of a year, just before the winter season.

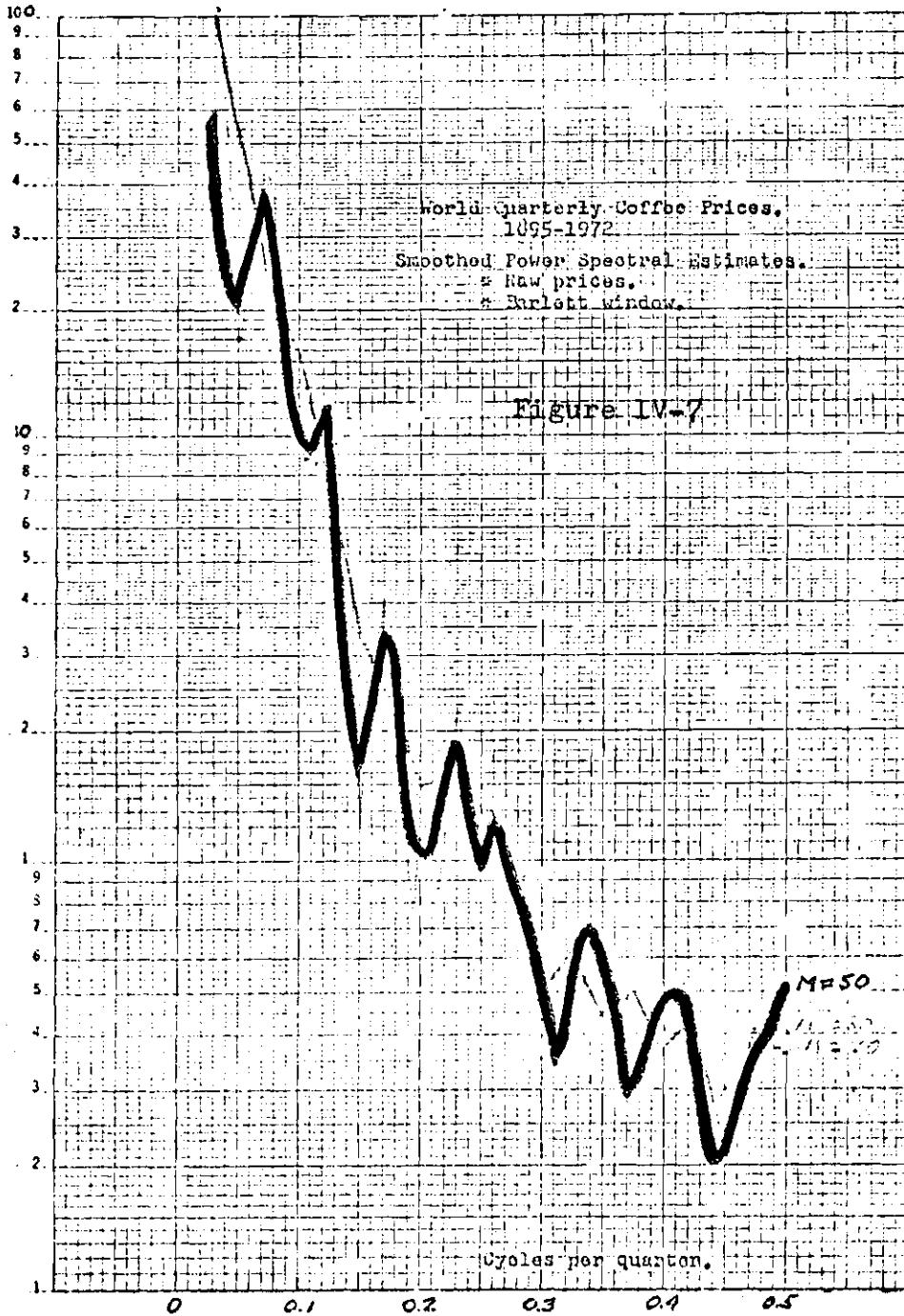


Figure IV-7. Spectral Plot of Quarterly Coffee Price.

expansion, an estimation for the prices is given by

$$\hat{P}_t = a_0 + \sum_{j=1}^{\infty} a_j \sin\left(\frac{2\pi}{P_j} t + \phi_j\right)$$

where  $a_0$  is the mean of the series, each  $a_j$  is a constant proportional to the power of the spectra at each frequency band  $j$ ,  $P_j$  is the period of each component and  $\phi_j$  is the lag between each frequency and the fundamental.

The following equation generated the pattern exhibited in Figure III-8.

$$\begin{aligned} \hat{P}_t = & 12 + \left\{ 5 \sin \frac{2\pi t}{32} + 3.75 \sin \left( \frac{2\pi t}{16} - 1.18 \right) + \sin \frac{2\pi t}{8.8} + \right. \\ & + 0.67 \sin \frac{2\pi t}{4.5} + 0.11 \sin \frac{2\pi t}{2.2} \left. \right\} + \\ & + \sin \frac{2\pi t}{6} + 1.05 \sin \frac{2\pi t}{3.2} \end{aligned}$$

where the  $a_j$ 's are the power densities shown in Table IV-1, multiplied by a factor of ten, and 12 is the mean of the actual price series in cents per pound. As depicted in Figure IV-8, the estimated series compares very favorably with the real price series with respect to period, shape, number of peaks, and amplitude. Naturally, the above combination of terms is just one among several other good alternatives.<sup>12)</sup> Nevertheless, the result indicates that a long cycle

<sup>12)</sup> Given the above combination of cycles, a 'best' fit could be easily obtained by

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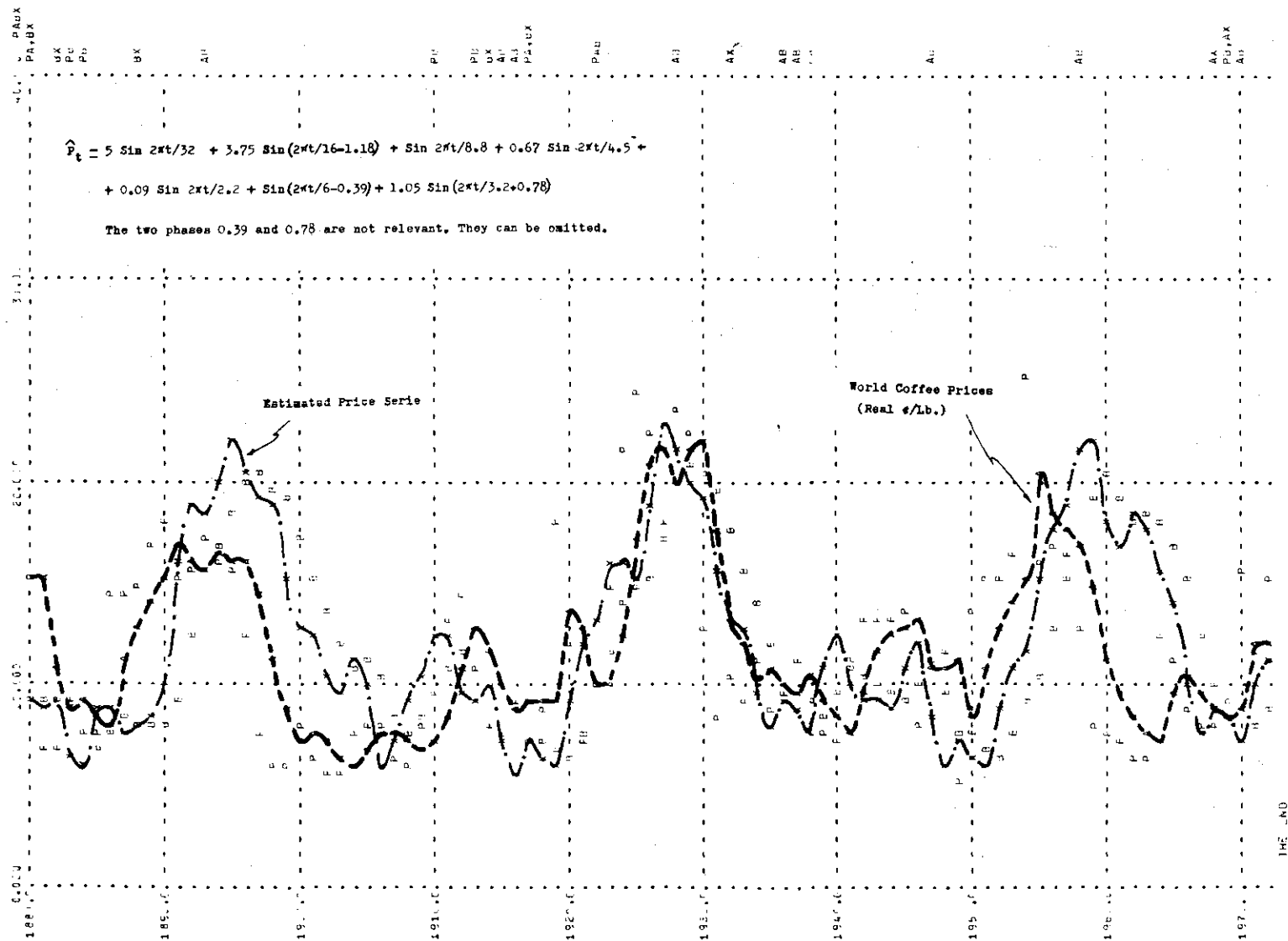


Figure IV-8. Actual and Estimated Price Series.

of around 32 years, combined with a lagged harmonic of 16 years, may indeed form the major coffee cycle.

## 2. Behavior of Production

Further confirmation of the existence of a very long cyclic movement appears in Figures IV-9 to IV-11. Figure IV-9 presents five year moving averages of Brazilian production, plotted on a logarithmic scale. The other two figures display the spectral densities generated by the same series and the spectral with confidence bands, respectively. These plots exhibit the peaks listed in Table IV-4.

Table IV-4. Peaks in Spectral Plots of Brazilian Production (30 lags)

1856-1972

Midpoint Frequency ( $\pm 0.00833$ ) cpy	Approximate Period (years)	Range of Period (years)	Chance that Peak is not Spurious
0.033	30.30	24.19, 40.54	80%
0.145	6.89	6.52, 7.32	Low
0.320	3.12	3.05, 3.21	90%

Figure IV-12 presents the spectral plot of the annual price series together with the spectral plots of the Brazilian production at 20, 30 and 40 lags,

the use of a least square method or any other standard forecasting procedure. See Brown, Smoothing, Forecasting and Prediction of Time Series.

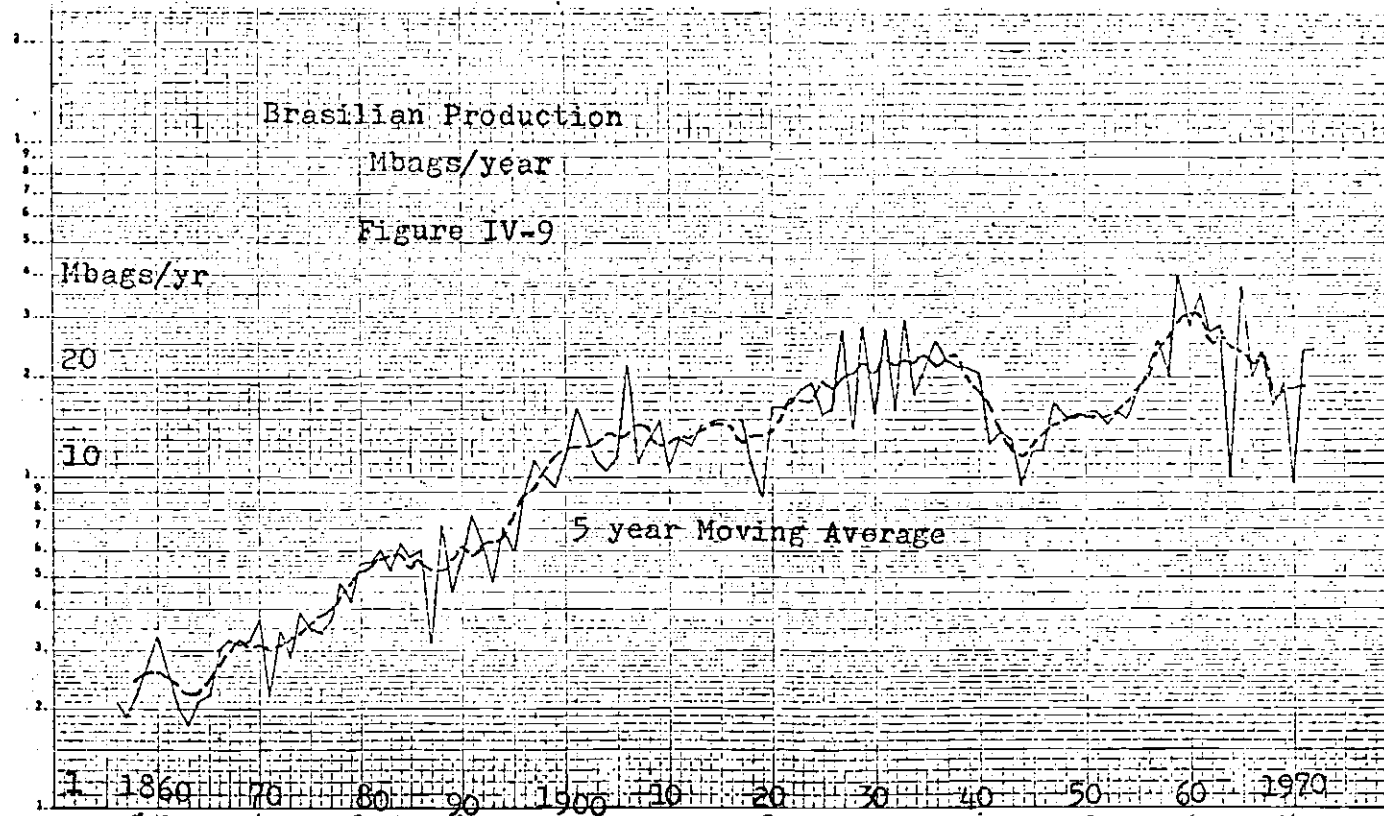


Figure IV-9. Brazilian Production.

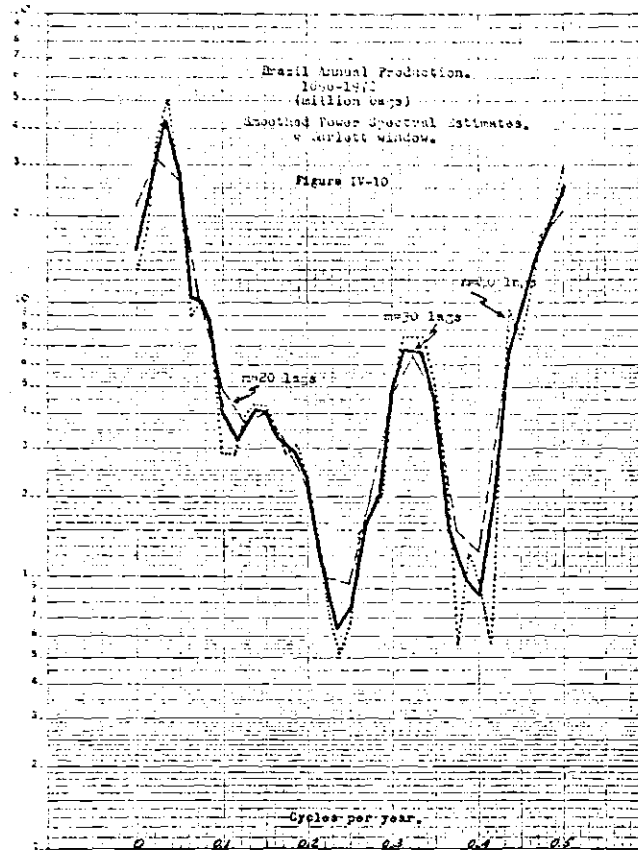


Figure IV-10

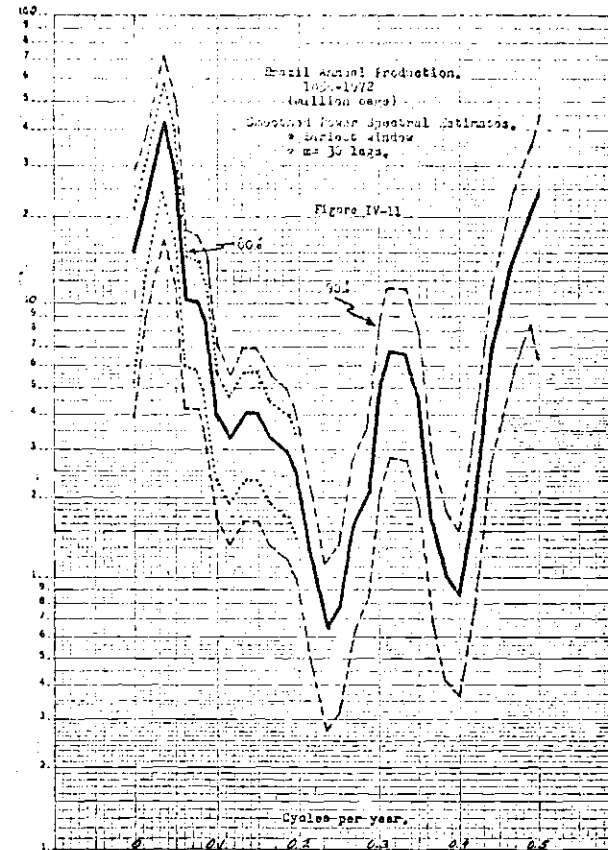


Figure IV-11

Spectral Plots of Brazilian Production



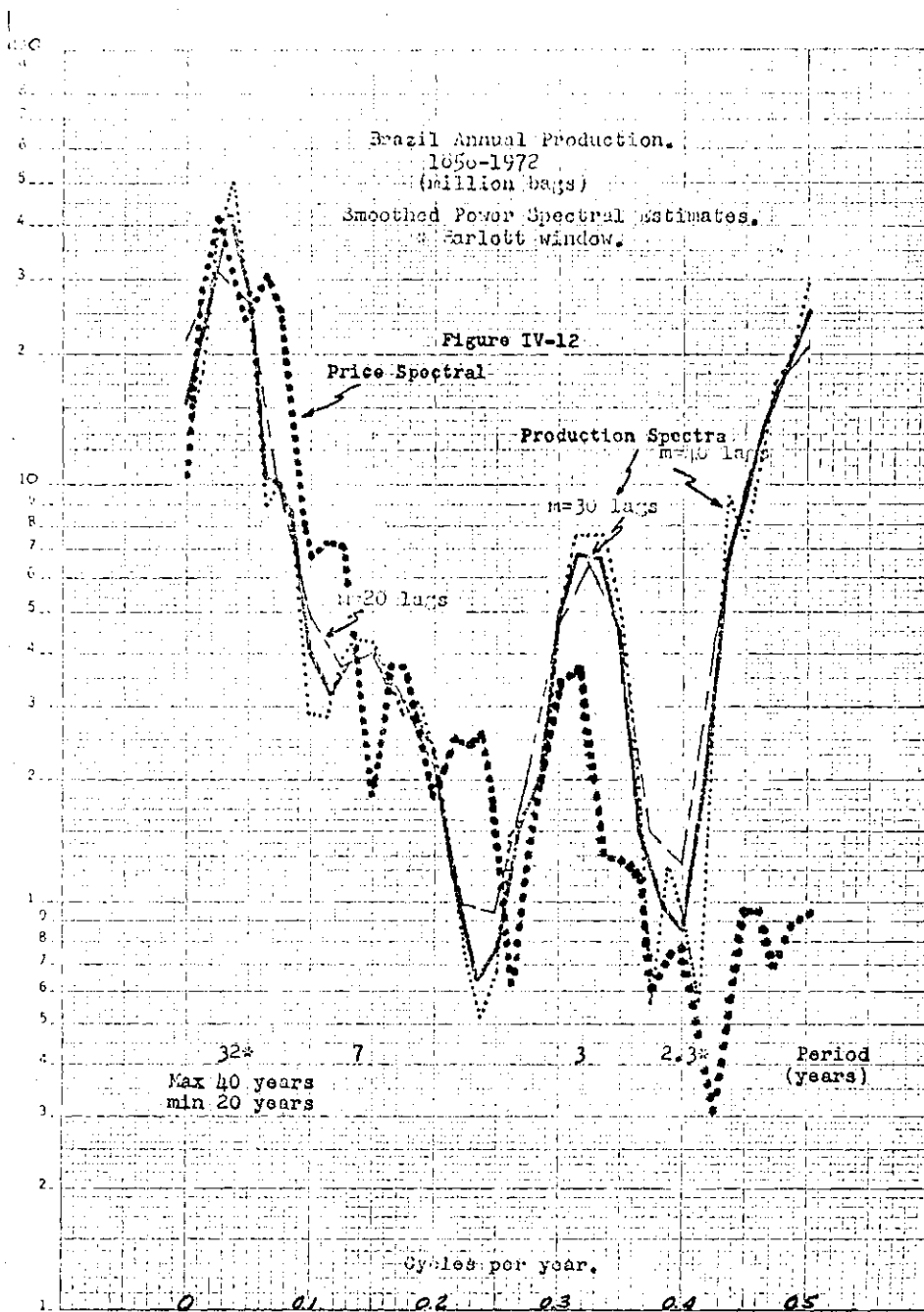


Figure IV-12. Spectra of Production and Price Series.

respectively. The two spectra have remarkable similitude with respect to power distribution, shape and peaks. Due to the lesser number of data points in the Brazilian production the resolution of the spectral plot at the lowest frequency is not as good as in the price series, and a lower profile is displayed by the higher harmonics at about 16 and 2.2 years. Furthermore, the Brazilian production spectra do not exhibit harmonics at 8.8 and 4.4 years, but instead show a flat bump at about six or seven years and the total width of the band includes a harmonic at 8.8 years. Certainly the resolution provided by the spectra is poor, but the lucky coincidence of the plots about power distribution at roughly equal frequencies and the presence of harmonics gives additional confidence to postulate these cyclic movements in the world coffee economy.

On the other hand, the plots depict two differences worth mentioning. First, the three-year cycle has twice as much power in the production plot than in the price spectra, and second, the production pattern is strongly affected by a wide variety of higher order frequencies as indicated by the biological cycle of the coffee tree, by climatic disturbances and several other random events which directly impact on the production pattern, and which have a more indirect and delayed effect on price developments.

#### E. Cyclic Movements in the World Coffee Economy

This chapter provides strong evidence to claim the existence of several fundamental cycles embodied within the world coffee behavior. Table IV-5 presents a summary of our findings and identifies each cycle by a given 'number-name,' its period in years. Thereafter, coffee cycles will be referred with this

Table IV-5. Cyclic Movements in the World Coffee Economy

Cycle Name (years)	Probable Period Range (years)	Power of Cycle	Confidence	
			Chance Peak is not Spurious	Harmonics (years)
32 }	30 - 36	0.500	80%	16, 8, 4, 2
16 }	15 - 18	0.375		
6	5.8 - 6.3	0.100	80%	1.5 ~
3	3.16 - 3.50	0.105	90%	
2	2.46 - 2.54	0.009	80%*	

\* 80% in the 1825 - 1946 price and relative price index series. Much lower chance in the other time series studied.

number, which is a rounded approximation of the actual period of the cycle in years.

## CHAPTER V

### THE WORLD COFFEE PRODUCTION SECTOR AND THE THIRTY-TWO YEAR COFFEE CYCLE

The world coffee production sector contains ten major feedback loops which link world price with land expansion, production rates and world supplies. A diagram of the sector appears in Figure V-1.

This chapter presents evidence that the world coffee production sector causes a long price cycle of about 32 years combined with a sequence of harmonic movements of higher frequency.

#### A. Introduction

Behavior in a dynamical model such as the coffee system is produced by both internal structure and exogenous disturbances. Internal structure in a dynamical system consists of a set of coupled feedback loops, each of which describes a closed chain of causes and effects. The operation of feedback loops under the influence of exogenous disturbances generate time trajectories or "behavior" of the variables in the system.

Figure V-2 is the loop diagram of an example of a feedback loop in the coffee system. It shows the dynamics of the International Coffee Agreements (ICAs), agreements that tend to be established as prices fall and to collapse as prices rise. Assume world supplies are rising above world demand; then the



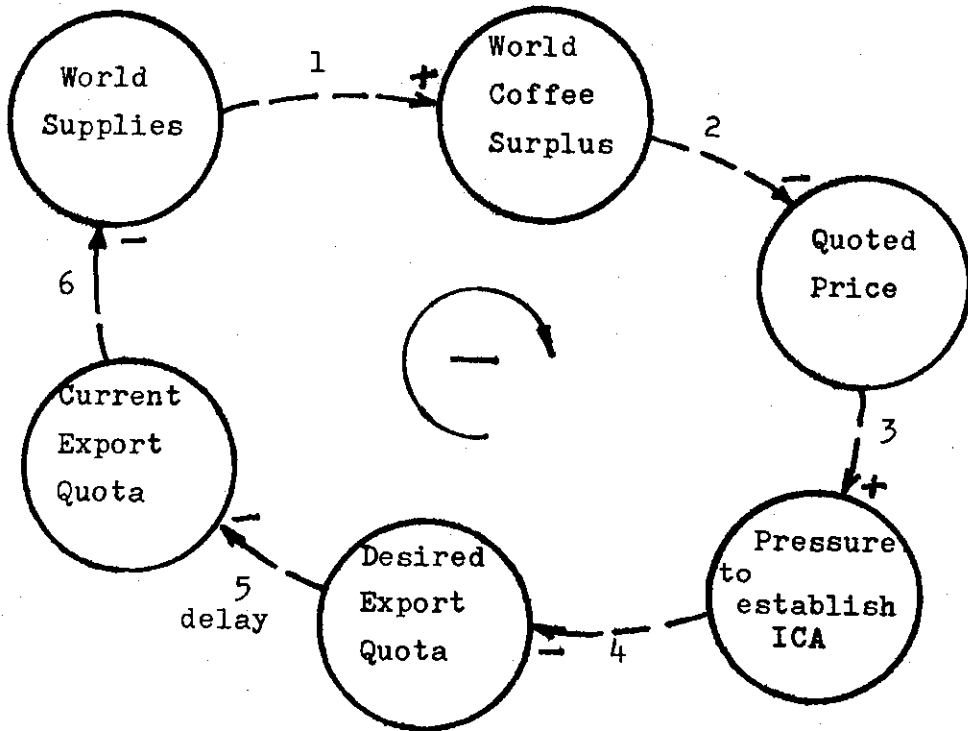


Figure V-2. Dynamics of ICAS.

surplus amount of coffee in excess of demand rises (arrow #1). Suppliers, anxious to allocate their abundant stocks among customers, will tend to compete against each other. They will offer discounts to traders who buy a portion of their coffee surplus. Quoted prices then fall (arrow #2). As prices fall, the foreign coffee receipts of the producing nations rapidly deteriorate. Hence, pressures gradually build up among the most urgent producers to establish a joint system of export quotas and stock retention (arrow #3). The stronger the price fall, the higher the pressure to sign an agreement with lower export quotas will be enforced (arrow #5). Note the delay to carry out negotiations. Hence, the flow of coffee supplies to the marketplace diminishes (arrow #6).

The description initially assumed rising world supplies. In this case the operation of the loop resulted with a reduced amount of world supplies. Had we started the loop with falling supplies, prices would have risen and nations would have become less urgent to establish or enforce the ICA's pacted quotas. The effective level of quotas would then have increased, bringing additional supplies into the market.

The above type of feedback is called a 'negative' loop; it generates a pattern of behavior in which the variables involved tend to swing up and down around a certain value, i.e., oscillatory behavior. Conversely, a feedback loop which generates sustained growth (or decay) is called a 'positive' loop. This section describes in detail some examples of these types of loops within the coffee production sector.

The following section presents the main feedback loops embodied within the structure of the coffee production sector. Each feedback loop is described by a short paragraph, then the loop is graphically represented in a companion figure. A more complete description of the assumptions made to build each one of the postulated feedback loops appears in Appendix B-I, which is divided into numbered sections. The number which appears underneath the variables in the loops shown in this chapter refer to the section(s) in the appendix which best describe the concept.

Here is a general explanation of the characteristics of loop diagrams:

- (a) Each loop consists of 'nodes' linked by 'arrows.' A node is a variable that changes through time, and produces effects on other variable(s). An arrow

from one variable to another indicates that the first variable affects the second.

- (b) Effects (arrows) can be positive or negative. A positive effect means that an increase in the first variable causes a rise (or avoids a fall) in the second. A negative effect means that an increase in the first variable causes a fall (or avoids a rise) in the second, i.e., production rates affect stocks positively; but sales affect them negatively.
- (c) Each effect occurs after an elapsed period of time. A rise in production does not immediately generate higher stocks, because the amount produced has to be packed, shipped and distributed before it actually arrives into the storage place. Thus each arrow in a loop usually includes a time delay. Sometimes, delays will be short, sometimes longer.
- (d) All other variables that do not appear in a given loop are assumed to remain unchanged.
- (e) Each loop is given a sign. A positive loop (+) is a loop that generates sustained growth or decay. A negative loop (-) is a loop that attempts to control a variable within certain limits, around a target value. Negative loops often produce oscillatory behavior.

## B. Feedback Structure of the World Coffee Production Sector and the Thirty-Two Year Coffee Cycle

The World Coffee Production Sector consists of ten major feedback loops. Each one of these loops performs a different function and generates a special type of behavior over time. When the feedback loops are coupled together, the



structure displays a long cycle of about 32 years of duration combined with harmonic movements of higher frequency.

Each loop is given a name that describes the loop function. The postulated feedback structures that form the coffee production sector appear in the following order:

- Loop P1: Supply of Labor, Land Expansion and World Coffee Tree Capacity
- Loop P2: World Supply, World Coffee Price and Tree Capacity Expansion
- Loop P3: Coffee Export Rate
- Loop(s) P4: Maturing, Productive and Obsolete Stocks of Coffee Trees; Removal and Normal Obsolescence Tree Flow Rates
- Loop P5: Abandonment of Coffee Trees
- Loop P6: Effect of Obsolescence on Tree Planting Rate
- Loop(s) P7: Induced Tree Obsolescence Rate
- Loop(s) P8: Technological Innovations and Effective Yields
- Loop P9: Foreign Cash Reserves and Supplier Inventory Control Policy
- Loop P10: Export Quotas and ICAs

The coupling of loops P1 to P4 generates a coffee cycle of about 30 years. This behavior is primarily caused by the two loops that adjust tree capacity and prices, namely, P1 and P2; the two loops embody a long sequence of time delays, one of which is the period required for a newly planted tree to bear fruit. The simulated cycle of 30 years appears in Figure V-8, at the end of the description given for the four main loops.

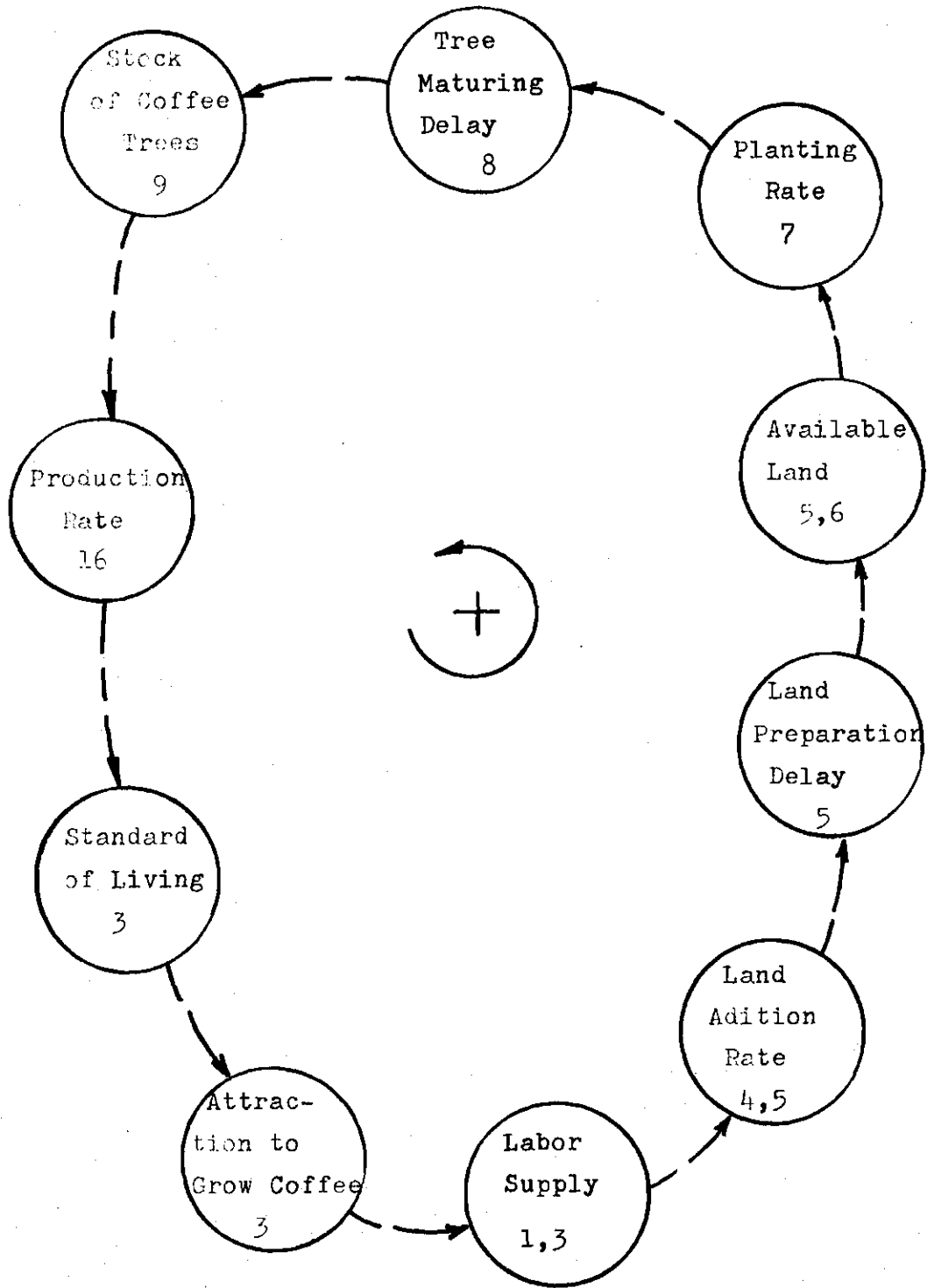


Figure V-3. Loop P1: Main Production Loop.

The addition of loops P5 to P8, i.e., abandonment, obsolescence, and effective yields, distort the thirty year cycle. In particular, abandonment of trees introduces a harmonic of about 15 years into the main cycle, while induced obsolescence adds price unstability with wider oscillations. Figures V-12 and V-18 exhibit the effects caused by these loops.

The behavioral effects of loops P9 and P10, stock and quota (ICAs) policy, are described in a later chapter.

### 1. Main Production Loops and a Thirty Year Cycle

a. Loop P1--Supply of Labor, Land Expansion and World Coffee Tree Capacity: Feedback Description. The current supply of available labor is a major determinant in expansion of coffee acreage, because a rise in the supply of labor is a precondition to prepare new land and to plant trees. Newly planted trees mature four years later, period after which matured trees enlarge the total stock of coffee trees; finally, production of green coffee tends to rise. Coffee areas with large numbers of trees and high production rates normally receive special attention from governments, whose policies and programs give support to the coffee farmer. As a result, the standard of living and income per capita in those coffee areas tends to increase faster than in surrounding non-coffee regions, a fact which establishes both higher rates of population growth in the coffee zone and rising migratory patterns toward those coffee regions. Therefore, labor supply, and consequently acreage with coffee trees, tend to rise at a faster rate (Figure V-3).

Coffee is primarily a labor-intensive type of crop with labor costs

representing more than 70% of the total farm operating expenses. This clearly indicates the relevant role played by labor availability and supply when a farmer considers expanding his coffee acreage, planting new trees and cultivating them. In Brazil, a country with a high number of large farms, the relative scarcity of hired labor to plant and cultivate the trees (and not land availability), has created serious obstacles to promote the expansion of acreage in the past (Furtado [11], Arak [1]). On the other hand, in countries with small coffee plots, where the farmer uses his own family as a source of cheap labor, the expansion of capacity has generally been accomplished with less difficulty. Generally these coffee states tend to show high population densities and growth.<sup>1)</sup>

A second assumption made in the previous feedback loop relates production of green coffee and standard of living with the attractiveness of growing coffee. In the majority of the coffee-producing nations, the farmer can sell most of his production, if he wishes, to the official coffee institutions at a floor price. Thus, the farmer who chooses coffee as his way of living expects to get at least a minimum income, with almost no marketing effort on his part. Furthermore, with the exception of Brazil, during the last few years, proceeds from coffee foreign trade turn out to be one of the few key sources of capital to generate national economic growth. For this reason both governments and the official coffee institutions

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<sup>1)</sup> The coffee states in Colombia have families with six or seven children, on the average. In this country and the Central American nations which produce coffee, the supply of land may also play an important role in expanding coffee acreage. The author, however, has not found factual support to accept or reject this hypothesis.

have traditionally carried out policies which support, maintain and enlarge the pool of coffee growers as well as the planted capacity. The effect of these policies has been the improvement of the farmers' living conditions over and above the living conditions of farmers not living in the same coffee regions, a fact which can be easily shown by comparing coffee states in Brazil, (Sao Paulo and Parana), Colombia (Antioguia, Quindio, Caldas) with other rural areas in the same nations.<sup>2)</sup> The protection given by the government to the coffee farmer, together with the general belief that coffee farmers tend to get a higher standard of living and income, are reasons that compel farmers who live on suitable land to establish or expand a coffee plantation. Further, if the economic outlook of the coffee market appears attractive to the farmer, he will pay higher wages to get the additional labor required to expand his acreage. On the aggregate, then, the improvement of the living conditions of the coffee farmer tends to attract an increasing flow of new farmers and workers to coffee regions, a fact which tends to augment the supply of labor in the coffee sector.

b. Loop P2--World Supply, World Coffee Price, and Tree Capacity

Expansion: Feedback Description. A rise in world supplies above world demand tends to depress world prices. In the face of falling prices, governments adjust domestic price policy to prevent a rapid contraction of the nation's foreign reserves. Returns to the farmer fall. As domestic prices decay, coffee cultivation becomes less attractive to the farm owner, who will tend to reduce the

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2)

Political reasons, too, compel governments to give support to the large pool of potential voters in coffee zones (Nieto Arteta [20] ).

rate at which he acquires cultivatable land, and to divert a portion of his coffee acreage to other uses. Thus, available land to plant coffee trees gradually becomes more scarce. Planting of new trees is then reduced; four or five years later, a diminished flow of newly matured trees will add to the stock of productive trees, which will grow more slowly, or fall if removal of trees was higher than planting during the period. Consequently, both production of green coffee and stocks will tend to fall, a factor which creates a market with tight supplies. With long-run demand constantly growing, scareness is inevitable, and the system evolves into a new period with rising prices (Figure V-4).

A period of abundant and rising supplies causes low and declining market prices. Thus, as supplies rise above demand, aggressive competition gradually shifts from traders to suppliers who in the face of falling prices and income become more and more anxious to allocate their saleable stocks to the customers. Therefore, increasing discounts will be offered to those traders who buy a certain portion of the nation's marketable stocks, which means that prices will fall even more. The price crisis aggravates as traders' demand falls with decaying prices.<sup>3)</sup> Hence, during a period of falling prices, when supplies tend to run high and traders' demand shrinks more and more, abundance of green coffee gradually increases, causing aggressive competition among suppliers, who now will be willing to sell additional amounts at the lowest prices to restore a poor

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<sup>3)</sup> This is fully explained in the next chapter, within the context of the Supply of Storage concept. At the moment, it suffices to say that traders' stocks, coverage and then demand for green coffee tend to decay as prices fall, and vice versa. (See Figure VI-2 in Chapter VI.)

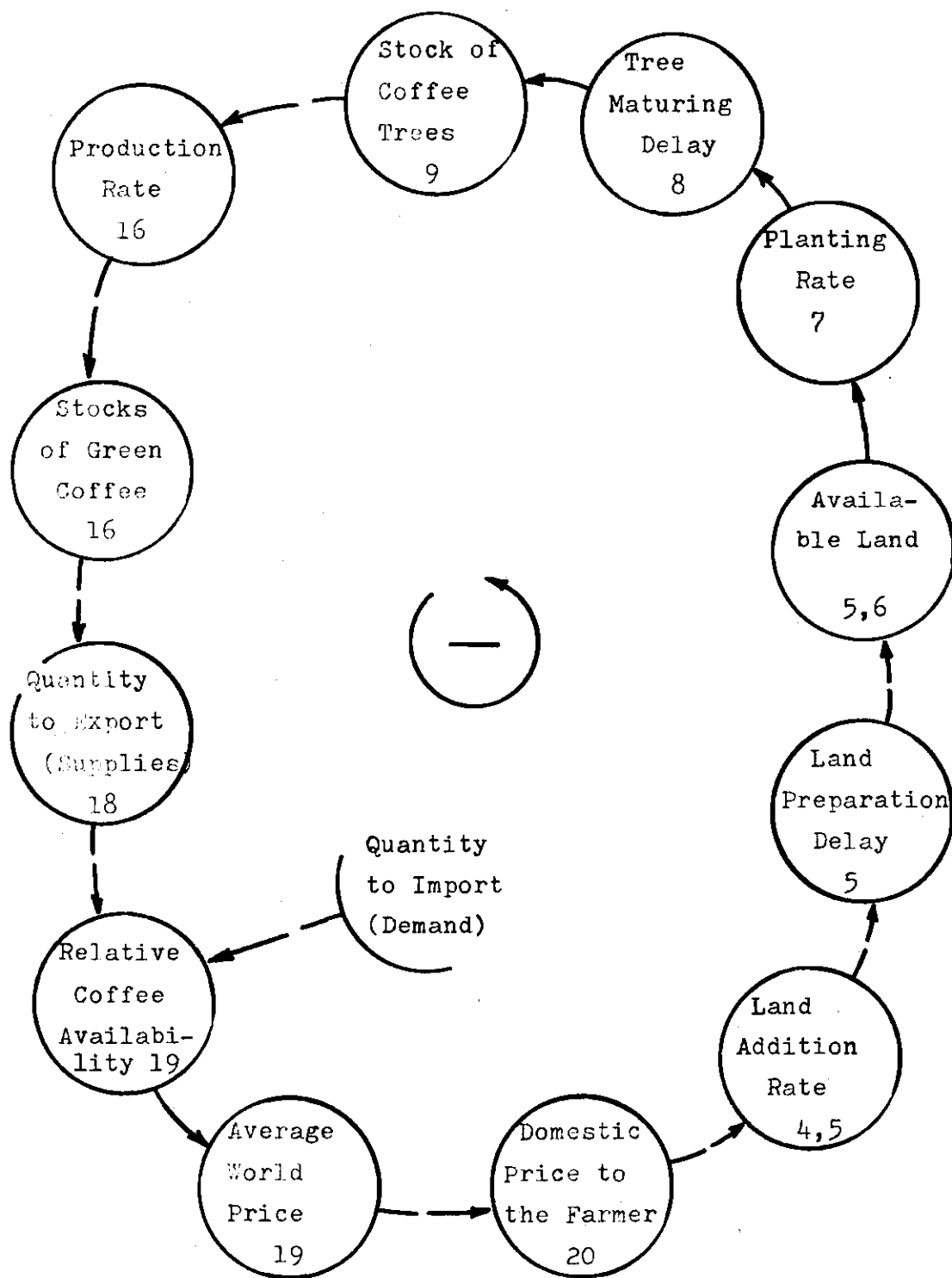


Figure V-4. Loop P2: Main Production Loop.

foreign cash position.<sup>4)</sup>

On the other hand, a period of low supplies and rising prices leads to increasing trader's demand, lower coffee availability, and further price increases. Figure V-5 shows the postulated effects of coffee availability. The depicted function could take several possible different shapes, depending on buyers' perceptions. If the reason causing a low flow of supplies is perceived as a temporary effect caused, say, adverse weather, small changes in relative supply will not tend to affect much world price; the curve is flat around zero (curve (a)). If on the other hand, small change in supplies and availability is perceived as an initial step leading toward a longer period with oversupply or scarcity, then a small variation in coffee availability will tend to affect drastically the formation of prices; the curve is steeped around the equilibrium point (curve (b)). An intermediate set of assumptions is depicted by curve (c). Curve (b) appears very plausible for the case of coffee in view of the anticipated formation of expectations about future long-range movements on both supplies and demand. This is the relationship used in the coffee model postulated here.<sup>5)</sup>

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<sup>4)</sup>The world coffee market is an oligopoly with differentiation of product (Geer [13]). Substitution of one type of coffee for another is always possible, with certain restrictions to provide blends of drinkable quality. Thus, some Arabic Brazilians normally compete against Milds during periods of low prices, and against Robustas during periods of rising prices. Mild and Robusta producers tend, however, to compete more often within each group. See Geer [13, p. 71].

<sup>5)</sup>There is no hard data to attest the values chosen in this relation. Discussion with individuals familiar with the coffee industry indicate that the function has reasonable shape and range.



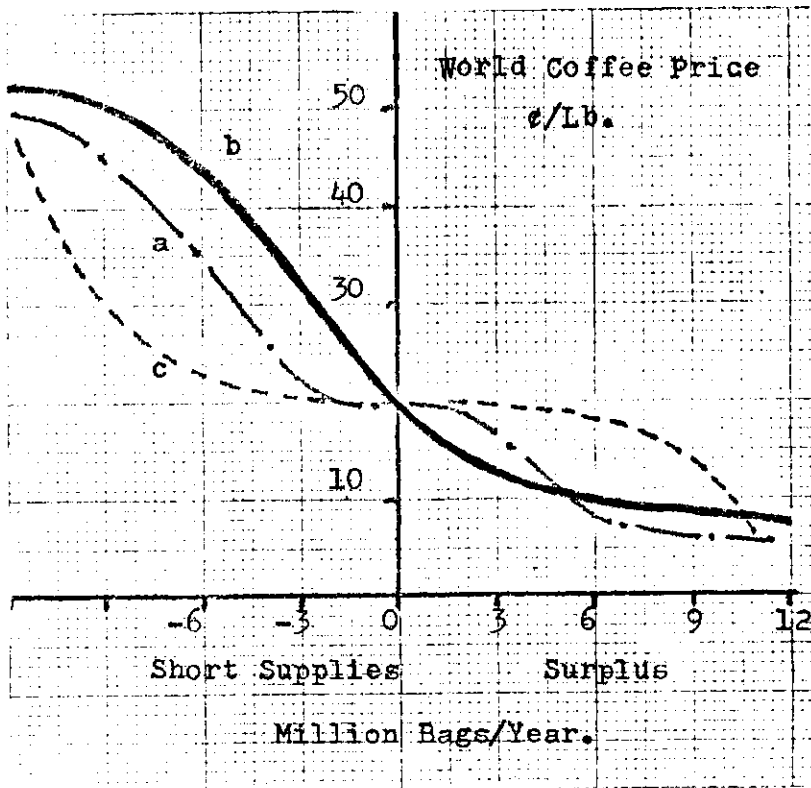


Figure V-5. Relative Coffee Availability.

Feedback Loop P2 assumes a direct relationship between world prices and domestic prices (Geer [13, p. 81], Keith [17, p. 304]). This means that rising or decaying prices generally lead to higher or lower domestic prices, respectively, after a delay caused by the time it takes to formulate a price policy, formulate a complex set of regulations, have them approved, and finally set up and implement enforcement mechanisms. After one or two years, at least, a new domestic 'equivalent' price, i.e. floor price, exchange rate, taxes, etc. will prevail throughout the nation.

Feedback loop P1 indicated a major, direct relationship between a higher

supply of labor and long run land expansions. Feedback P2 depicts, on the other hand, the adjusting effects of current domestic price and future farmers' price expectations on coffee land additions. Given a certain amount of labor (i.e. wages), and a level of prices with its direction of change, there always will be an amount of coffee acreage and trees which will return higher profits to the farmer than in any other crop. This amount of acreage is the desired extension of the total plantation [Arak, 1, p. 215]. We assume the desired amount of land in coffee can be described as a product of three functions:

$$\text{Desired Land} = \Phi (\text{labor availability}) \times f_1(\text{domestic price}) \times f_2(\text{domestic price change})$$

The net annual additions of hectares to cultivate coffee, is then given by a fraction of the difference between the desired total acreage and the amount of land currently planted with trees. Newly added hectares can not be used immediately to plant coffee. If the farmer is currently using them with other crops he will wait until the next harvesting period to collect cash and invest in coffee, and even then, he still will have to give rest to the land, add fertilizer, weed and prepare the soil. On the average, a time period of about two years may pass, before the land becomes ready to support coffee plants.

The rest of the feedback loop P2 has been previously described within the context of loop P1. The description of these relations will not be repeated here. However, the reader may take note of the long delays contained in the operation of both, loop P1 and loop P2. The maturing delay of four or five years is but one among a whole chain of similar delayed effects. These delays appear in Table V-1

Table V-1. Main Delays in Production Loops P1 and P2

Name	Approximate Number of Years	Description
Land Correction Time	2 <sup>*</sup>	To adjust land to target value
Land Preparation Delay	2 <sup>*</sup>	Period required to prepare land.
Planting Correction Time	2 <sup>*</sup>	To achieve desired number of trees.
Tree Maturing Delay	4	Time required to bear fruit.
Distribution Delay	1	Period to wash, dry, pack, ship, and distribute the picked berries.
Average World price Formulation	1	Time to perceive current world price changes and their effects on foreign receipts.
Government Domestic Price Policy and Control	2	Period of time required to adjust domestic coffee policy.
Average Domestic Price	1	Period required by the farmer to perceive the effects of new domestic policy.

\* The behavior of the Dynamic Coffee Model postulated in this research is not sensitive to  $\pm 100\%$  change in the values of these three delays. When the delays were reduced to one year, the model still exhibited a long cycle of about 30 years. A value of 0.5 years for each of them produced a cycle of 29 years. Similar results hold for the other delays; the maturing delay does not produce major change within a  $\pm 25\%$  variation.

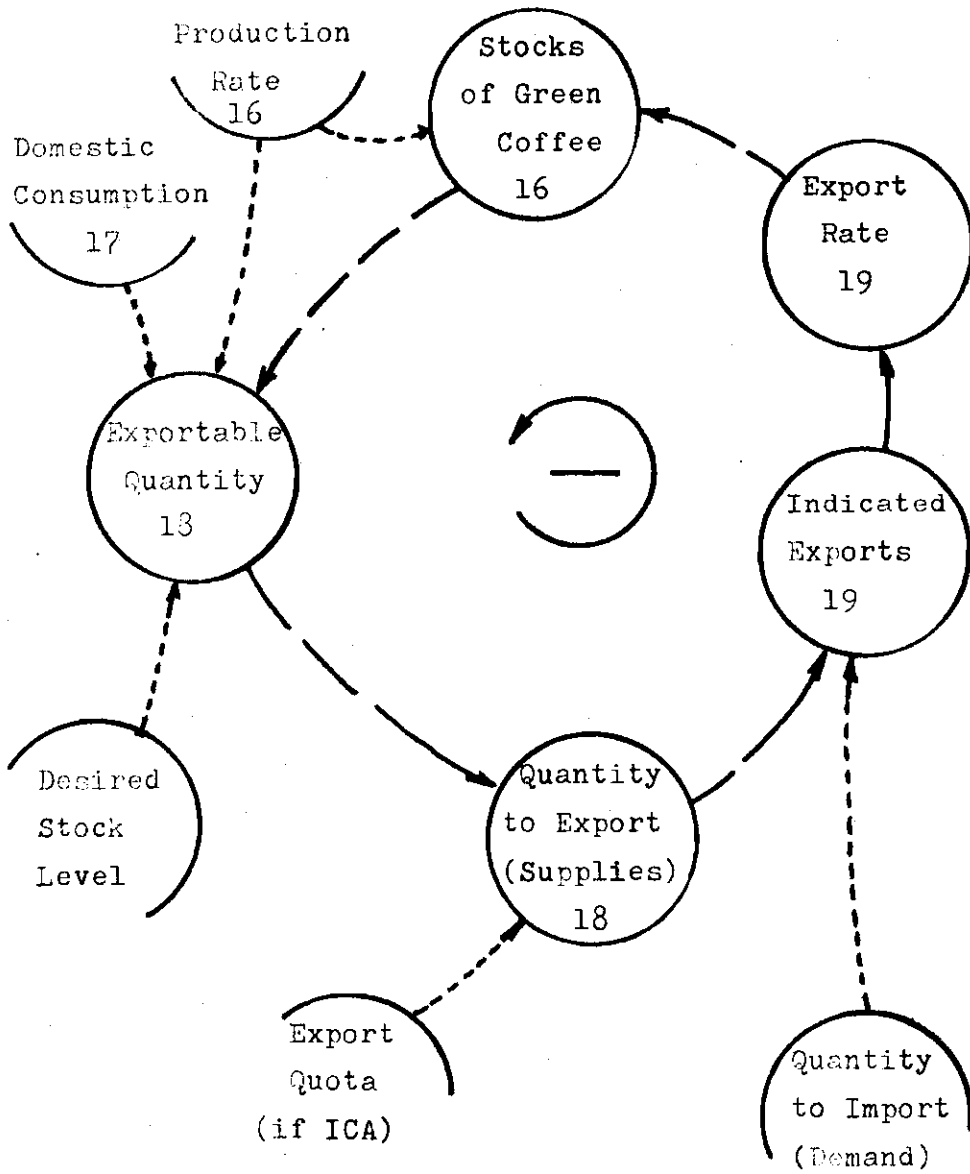


Figure V-6. Loop P3: Export Rate.

and are fully explained in Appendix B-I.

c. Loop P3--Export Rate: Feedback Description. The flow of green coffee exported during a year depends on both the amounts of coffee offered to the international market by the producer, and the trader's demand for coffee at the current price. In turn, the volume of supplies offered to be sold depends on both the actual rate of production and the current level of stocks, and also, on the nation's foreign coffee policy.<sup>6)</sup>

The quantity offered at the market place is given by the amount of exportable production plus the excess of stocks above a target value. The difference between the supplied quantity and the current demand establishes the current level of prices at which traders would be willing to buy the amount of coffee demanded (loop P2, and Figure V-4). When supplies surpass demand, suppliers will tend to offer discounts to traders on the condition that they buy additional amounts of green coffee. Hence, exports tend to rise above demand. On the other hand, if supplies are short with respect to demand, traders will tend to pay a premium to those suppliers who sell additional portions of their reserve stocks. Hence, exports will tend to rise above the quantity originally supplied to the market. Thus, on the aggregate, the current export rate will tend to be an amount lower than the quantity originally demanded by the traders, but higher than the amount originally supplied by the producer. An average between the two extreme

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<sup>6)</sup> Export quotas under ICA's and the nation(s) stock policy, among others. See feedback loops P9 and P10 in this chapter.

quantities appears to be a good representation of the supplier-trader price-exports bargaining decision process.

tities appears to be a good representation of the supplier-trader price-exports bargaining decision process.

d. Loop Set P4--Maturing, Productive and Obsolete Stocks of Coffee

Trees. Removal and Normal Obsolescence Tree Flow Rates: Feedback

Description. Trees completing a gestation period of about four years are Maturing Trees. A rise in the flow of planted trees during a year, over and above the rate at which trees become matured each year, causes a rise in the total stock of Maturing Trees, otherwise the stock of trees will tend to remain unchanged on fall. In turn, an increase in the amount of trees in this group tends to augment the number of trees which each year reach maturity. As more trees depart from this tree-group, the total number of maturing trees tends to decrease. Conversely, a decline in the actual number of trees in the group, causes a decay in the tree maturity rate, a fact which tends to counter-balance the original fall in the stock of maturing trees (Figure V-7-a).

Highly-Productive-Trees are matured trees with rising and high yields. On the average, the yield of a tree rises and reaches a plateau over a period of twelve years. A rise in the flow of newly matured trees per year above the flow of trees which each year become older with falling yields (i.e. the normal obsolescence tree rate), causes an increase in the total stock of highly productive trees. Otherwise, the stock of productive capacity will tend to remain unchanged or decay. In turn, a rise in the number of trees in this group tends to produce

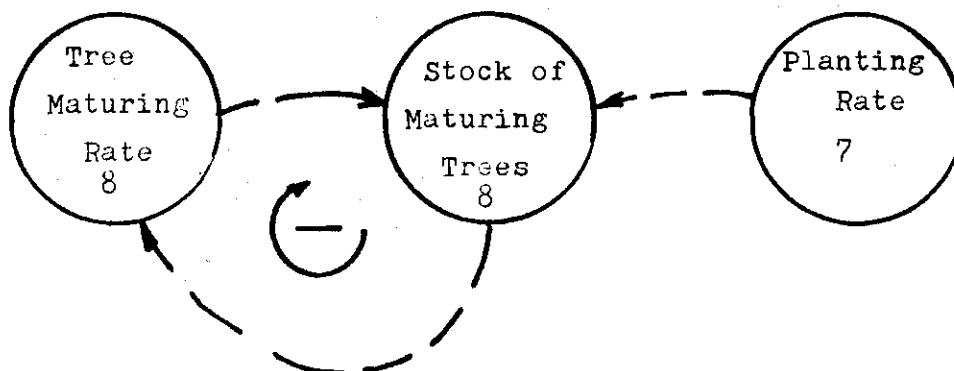


Figure V-7-a. Tree Maturing Rate.

higher obsolescence rates which tend to restrain further growth in the number of highly productive trees. Conversely, a fall in the current number of trees in this group, causes a reduction in the flow of trees obsoleted per year, the Tree-Obsolescence-Rate, which tends to counterbalance the original decay in the stock of highly productive trees (Figure V-7-b).

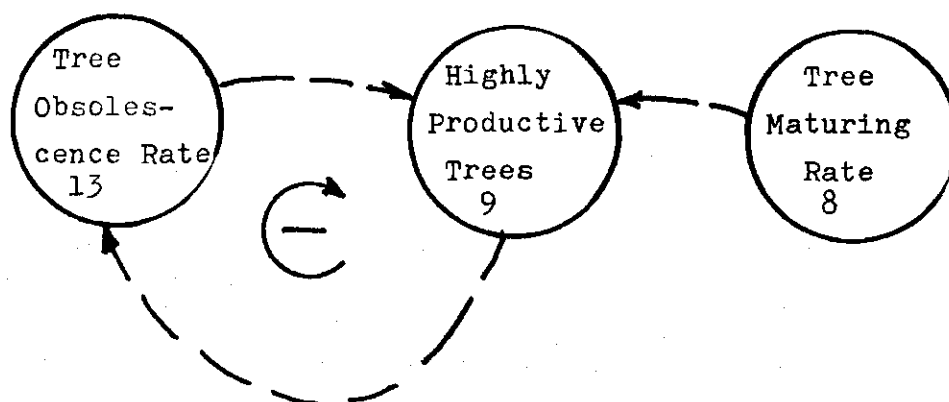


Figure V-7-b. Tree Obsolescence.

Obsolete trees are older trees with declining yields. A tree may stand as obsolete capacity for 16, 20 or more years under normal weather conditions. As the tree obsolescence rate rises above the rate at which trees are removed each year (the Tree-Removal-Rate), the stock of obsolete capacity increases. On the average, then, the flow of trees removed per year will also rise, a fact which produces a negative effect on the stock of obsolete capacity, which tends to fall. Conversely, a fall in the stock of obsolete trees generates a reduction in the Tree-Removal-Rate, a fact which tends to restrain the initial fall in the stock of obsolete trees (Figure V-7-c).

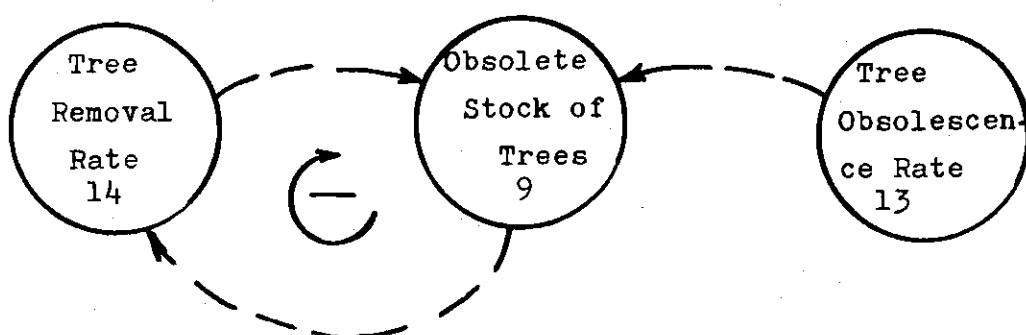


Figure V-7-c. Tree Removal.

The Tree-Removal-Rate may or may not be a function of world prices. Removal costs are high, and in addition, the farmer in many coffee areas of the world does not have attractive substitute crops or land uses open to him. During a period of falling prices, the farmer will find it more beneficial to abandon a fraction of his older and low yield trees than to remove a portion of his obsolete capacity (Arak [1]).



Loop structures P1 to P4 form the main feedback loops of the World Coffee Production sector. When these feedback loops are coupled together and each one of the postulated relations is translated into mathematical statements, the structure can be tested on a computer, to see the behavior it is able to produce.

Figure V-8 shows the behavioral pattern exhibited by the four main loops when the structure was simulated over a long period of years (1890-2000). This behavior shows a cycle in prices, production and stocks of about 30 years' duration.

To test the behavior of the model, throughout the period, the model variables are initially at equilibrium. This means that the annual green coffee usage rate (exports plus domestic consumption) is originally made equal to the annual green coffee production rate. Hence, stocks of green coffee do not change in any direction. Similarly, planting rates are made equal to removal tree rates; hence, the total stock of trees remains constant. These conditions are maintained throughout a period of ten years, from 1880 to 1890, years during which none of the variables plotted exhibits dynamic behavior in Figure V-8.

At the beginning of year 1890 the system receives the impact of an exponential demand. This is shown by the letter 'u' in the plots, which stands for 'required exports.' This quantity, rises exponentially, from an initial value of about 8 million bags during 1890, to about 58 million bags during 1970. The behavior generated by the feedback structure is direct consequence of the relations depicted by each loop.

A sudden rise in exports depletes stocks and diminishes relative availability of coffee at the marketplace. Hence, price rise (loop P2 and Figure V-5). As world prices increase, domestic price policy is adjusted, and after a delay,

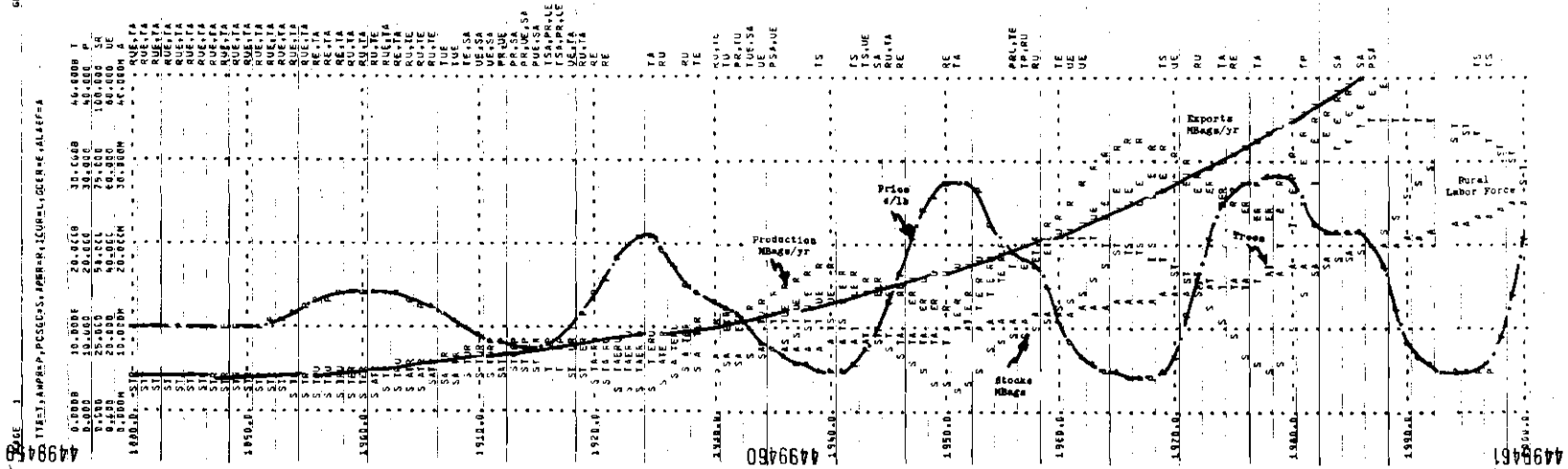


Figure V-8. Behavior of the Four Main Production Loops (P1 to P4): A Thirty Year Price Cycle.

domestic prices to the farmer rise too. Acreage to plant coffee trees grows and additional trees are planted (loop P2). World prices, however, keep rising, since newly planted trees do not produce. Similarly, the rising prices tend to improve the farmer's standard of living, hence additional labor is attracted to grow coffee, a fact which allows rapid expansion of acreage (loop P1). By the year 1900 prices peak and stay there for a short number of years. Prices reach their maximum value, because the trees originally planted have already matured and are producing rising yields. Production then tends to rise above exports, and stocks begin to recover (loops P1, P2, P3).

The rise in both production and stocks creates abundant supplies at the marketplace. Hence, world prices fall. As prices fall, excess capacity is not adjusted fast to keep production near world requirements, that is, tree removal rates do not generally depend on prices (loop P4-c). Hence, the only chance to reduce capacity will come through declining planting rates, which fall as prices decay. By the year 1915 prices are the lowest, while stocks peak.

The low level of prices has induced farmers to reduce land expansion. Planting rates then tend to be lower than removal rates; therefore, total tree capacity falls (around the year 1916). By this time, the average age of the stock of trees will tend to be older. Thus, older trees with declining yields together with a reduced number of trees cause a fall in production rates below world requirements; this is the reason to explain the fall in stocks of green coffee by the year 1918. World supplies then, become scarce, and hence world prices begin to rise.

The first cycle just described has a duration of about 26 years. The other cycles displayed by the same figure show periods of 28 and 30 years, respectively. The reason to explain this expanding period, lies in the nature of the pattern used to represent the required exports, the input to the model. Actual coffee exports since 1890 to 1975 show an 'almost' exponential function, which grows with time. The input used to create the simulated behavior, on the other hand, exhibits exponential growth. Initially, exports grow at a lower rate, from 8 million of bags/year by 1890, to 20 million of bags/year by 1930. Nevertheless, after an additional span of 40 years (by 1970), exports reach almost 60 million of bags/year. Hence, during the first cycle, the unbalance created by the rise in exports was smaller than that created during the second and third cycles. Hence, farmers were able to correct excess or shortage of capacity in a shorter period of time than during the other cycles shown.<sup>7)</sup>

## 2. Secondary Production Loops and Harmonic Cycles

a. Loop P5--Abandonment of Coffee Trees: Feedback Description. At each level of prices, there exist an optimal age beyond which it is not profitable to cultivate older trees. With declining prices, the farmer generally finds it more beneficial to abandon this portion of older trees than to remove it [Arak, 1, p. 215]. As prices fall, trees with declining yields tend to become less and less profitable; thus, the age at which the farmer will abandon obsolete trees

<sup>7)</sup> The model was also tested under a step increase in exports. Thus, originally, exports stay at 8 million bags/year; then, by 1890 they 'jump' to 40 million bags/year, and stay there for the rest of the period. In this case, all cycles exhibited a similar period of about 32 years of duration.

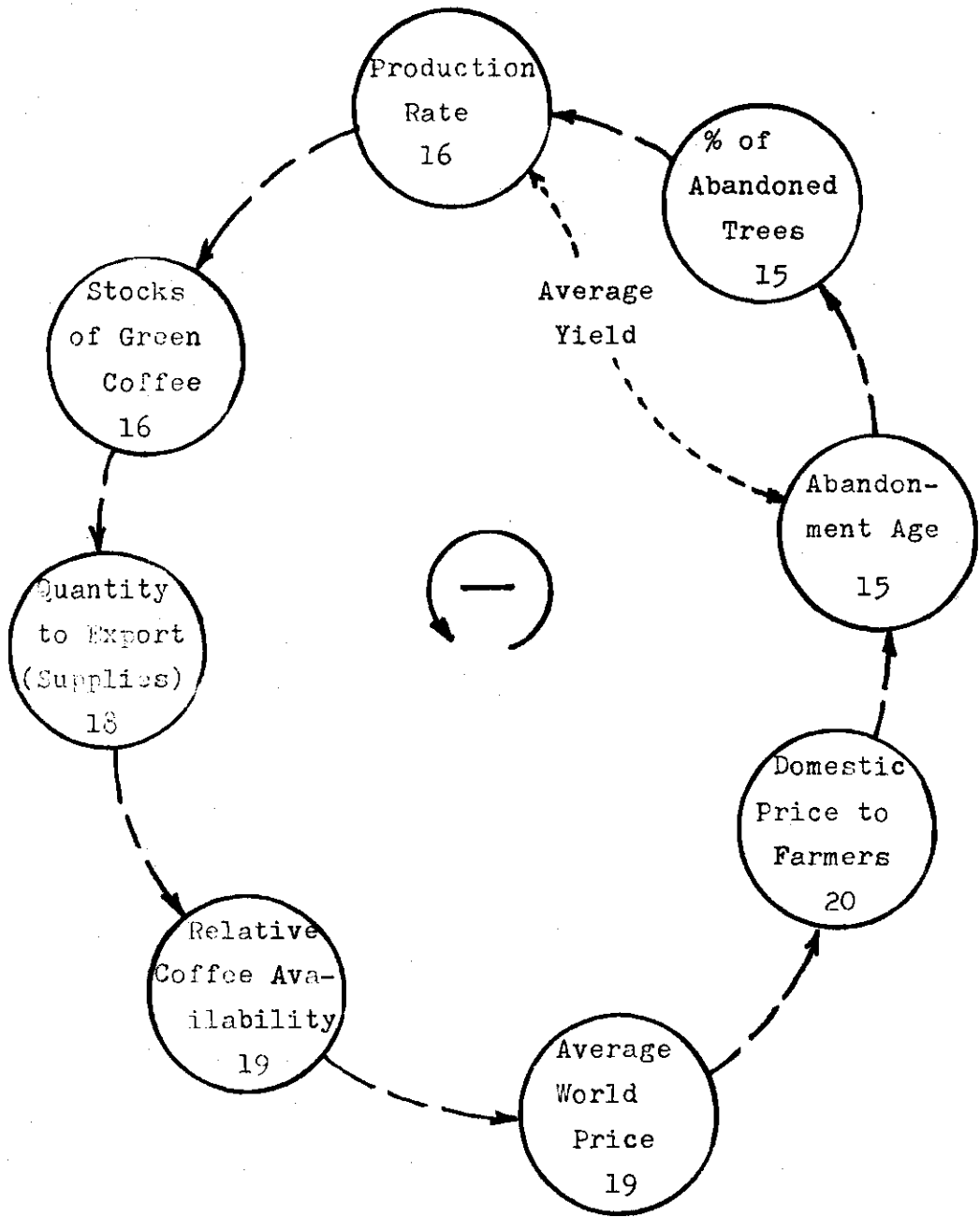


Figure V-9. Loop P5: Abandonment of Trees.

tends to become younger. The younger the age of abandonment, the larger the fraction of trees to be neglected. Therefore, annual production rates decay, stocks tend to become less and less dominant, and the quantity offered to export tends to fall. A reduction in worldwide supplies tends to create a rise in prices. Hence, shortage of domestic supplies together with government action to relax domestic price controls combine to produce rising domestic prices to the farmer (Figure V-9).

Abandoned trees are trees which are not cultivated, their surrounding area not cleared of weeds and their yield not picked. At lower prices, the farmer may find it beneficial to abandon a fraction of their obsolete capacity whose declining yields does not cover labor and fertilizer cultivation costs. Therefore, at each level of prices, there exist an 'optimal' age, beyond which the yield of the trees is lower than the cultivation cost of the tree. This age is the abandonment age. Figure V-10 depicts three different abandonment ages at three different price levels. The broken lines show the dollar-yield i.e. price-yield, of trees at different ages, and at prices  $P_{-2}$ ,  $P_{-1}$ , and  $P_0$ . As prices rise from say, a price  $P_{-2}$  to a higher price  $P_0$  the dollar yield of the trees gradually shifts upward.

The solid line on the same diagram, shows the annual cultivation costs per tree at different ages. Older trees require, generally, higher fertilizer costs than younger ones. Thus, annual cost tends to rise with the age of the tree. At a price  $P_{-2}$ , the intersection of the dollar-yield and the cost curves

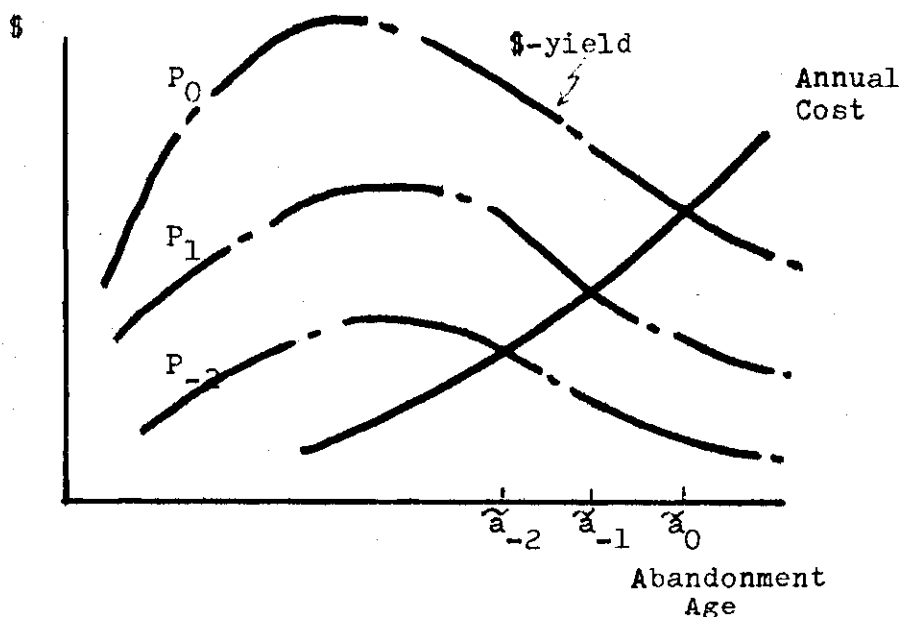


Figure V-10. Abandonment Age of Trees at Different Levels of Price.

gives the abandonment age  $\tilde{a}_{-2}$ . A rational farmer would not cultivate trees older than this age, as their annual cultivation cost rises above the returns per tree. Furthermore, as the level of prices increase from  $P_{-2}$  to  $P_{-1}$  and  $P_0$ , the 'optimal' abandonment age gradually becomes older; i. e.  $\tilde{a}_0$  is greater than  $\tilde{a}_{-1}$ .

The fraction of abandoned trees depends on the abandonment age  $\tilde{a}$  at the current price  $P$ . At very high prices, the age of abandonment tends to be also high; therefore, the farmer will tend to cultivate most of his trees and the fraction of abandoned trees is low. As prices fall, the abandonment age of trees will look gradually younger; therefore, more and more trees are neglected; the fraction of abandoned trees rises. At the lowest prices, on the other hand, the

optimal age of abandonment may tend to be too young. A farmer probably will never abandon trees with rising or high yields (Arak [1, p. 215]). Hence, as the abandonment age approaches the average age  $\bar{a}$  of the stock of trees, the fraction of abandoned trees tends to reach a maximum beyond which additional younger trees will not be abandoned. Section 15 of Appendix B-I fully describes the development of the fraction of trees abandoned as a function of the abandonment age. The appendix shows, among other things, that the shape of the function depicted in Figure V-11 follows from the assumptions made.

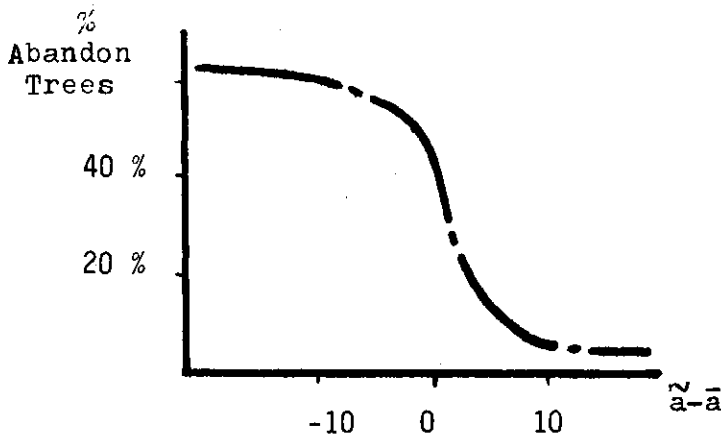


Figure V-11. Abandoned Fraction of Trees.

The addition into the World Coffee Production Model of the abandonment loop P5, introduces a lagged harmonic of about 15 years to the coffee cycle. Figure V-12 shows three price cycles of about 26, 31, and 30 years respectively. The harmonic of about 15 years can not be detected from a visual inspection. Nevertheless, the tendency of the price wave to fail and recover when prices are still high, undoubtedly suggest the presence of a lagged harmonic of about half



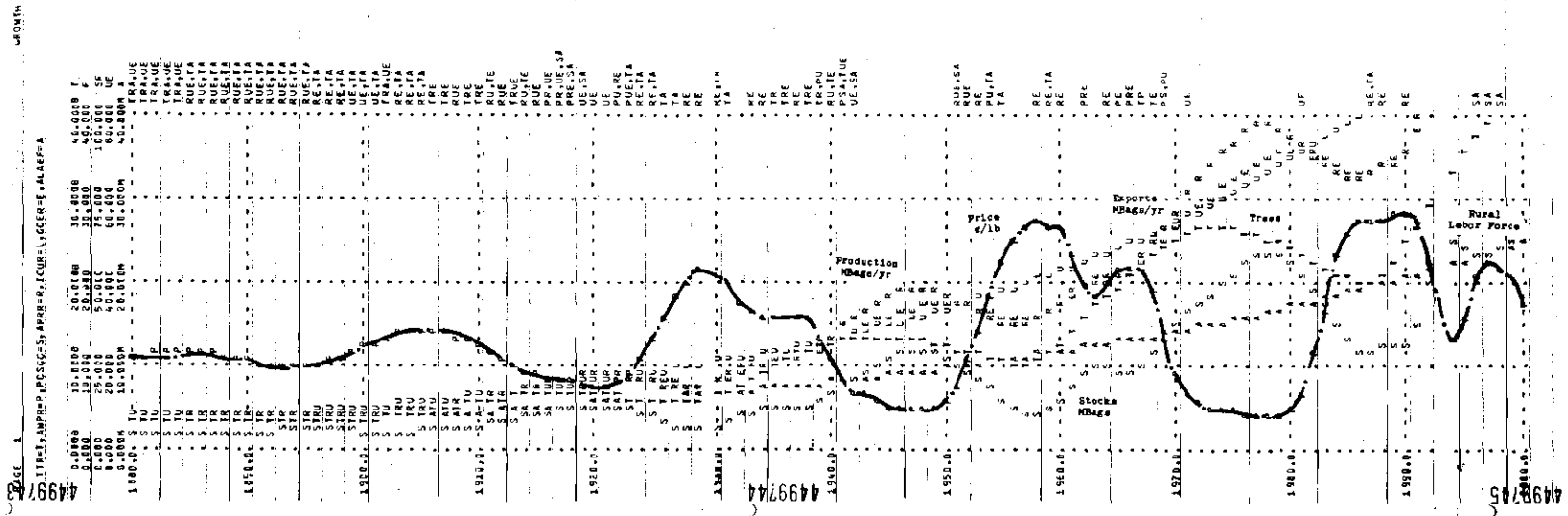


Figure V-12. Effect of Abandonment of Trees: A 16 Year Harmonic.

the period of the main cycle.<sup>8)</sup>

The above result is a logical consequence of abandonment loop P5 depicted by Figure V-9. The effect of this loop is to bypass the long delays involved in the main loops P1 and P2, namely, the land expansion and maturing delays. In fact, if prices fall, a farmer may almost immediately decide not to harvest a portion of his standing trees. Thus, production and stocks tend to fall more rapidly than in the case in which abandonment was not included. This is fully confirmed by visual inspection of the plots in Figures V-8 and V-12. In the first plot, with no abandonment, production and stocks fall over a period of about ten or eleven years; in the second, they both fall over a shorter period of around eight years.

b. Loop P6--Effect of Obsolescence of Trees on Tree Planting Rate:

Feedback Description. Tree Planting Rate, the number of trees planted each year, depends on the amount of available land and also, on the fraction of obsolete stock, Arak [1, p. 215]. A high fraction of obsolete and older trees, induces the farmer to plant new trees and renovate his plantation. Four years later the matured trees will pass to enlarge the stock of highly productive trees, a fact which tends to reduce the fraction of obsolete capacity and hence,

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<sup>8)</sup> The author found this feature when he built the estimated coffee price series from the spectral plots, in Chapter IV (See Figure IV-8 ).

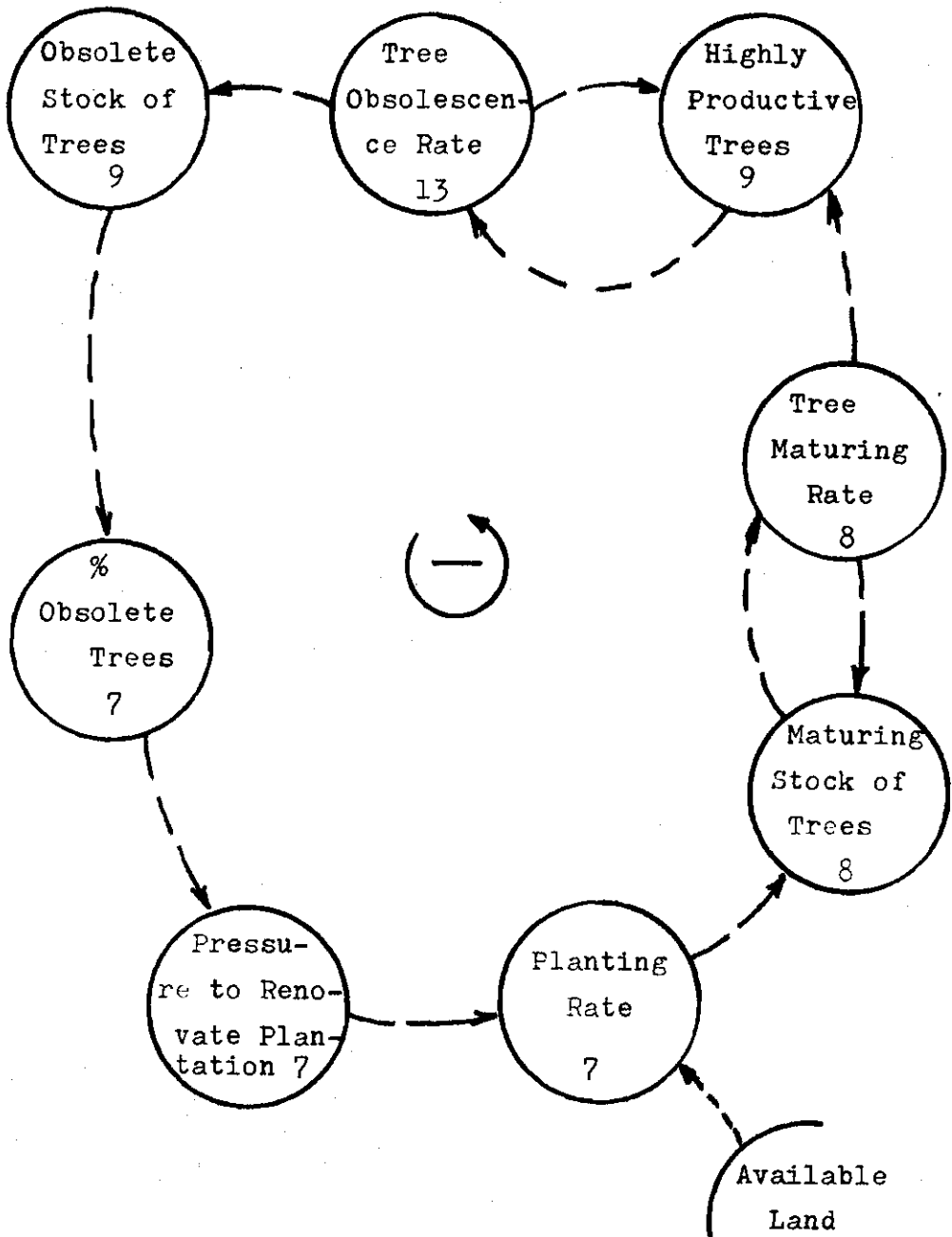


Figure V-13. Loop P6: Tree Flow Rates.

planting (Figure V-13).<sup>9</sup>

c. Loop Set P7--Induced Tree Obsolescence Rate: Feedback Description.

The addition of younger trees with higher yields to a plantation, tends to accelerate the speed at which older but still productive trees are obsoleted. A rise in the Tree Obsolescence Rate reduces the stock of highly productive capacity, but augments the stock of obsoleted trees. As more matured trees with high yields depart from the first group to enlarge the obsolete group, the average age of the trees in each one of the two categories tends to look younger. If planting rates are higher than removal rates, the average age of the productive trees will tend to change faster than the average age of the obsolete stock. In turn, the average yield of the productive trees will grow faster than the average yield of the obsolete stock. Hence, the ratio between the two (average) yields tends to rise. A time period will elapse before a farmer fully notes and appreciates the effects of a rising yield ratio. However, as the ratio increases, a portion of the more mature and highly productive trees will appear to him uneconomical to support; these trees will tend to be considered as obsolete capacity by the farmer. Hence, the Obsolescence Tree Rate tends to increase (Figure V-14).

An old tree with low and declining yields is an obsolete tree. If all the trees in a farm were able to produce the same yield regardless of age, soil and fertilizer used, then the farmer would probably never complain about his older

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<sup>9)</sup> Planting rate is also affected by the average age of the total tree stock. A farmer with older trees tends to promote planting; as the stock of trees gradually gets younger, the farmer will tend to reduce his rate of planting. See Appendix B.

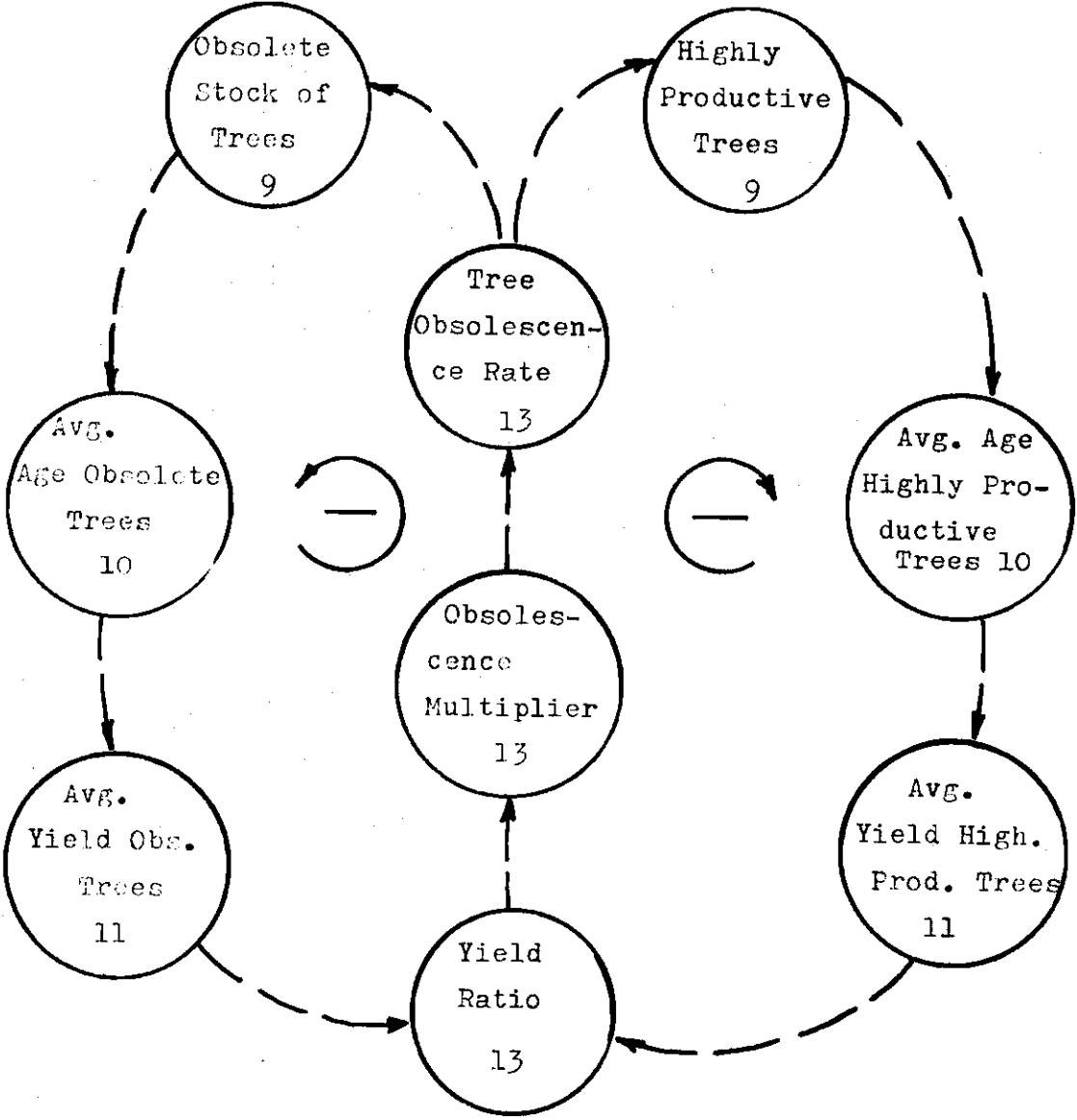


Figure V-14. Loop P7: Obsolescence of Trees.

and obsolete capacity. Unfortunately, trees get older, and the older they get the less productive and more costly they become; at the same time, young trees and new species with higher yields, tend to increase farmer's expectations about returns on investment and growth potential. With newly matured stock, higher yield trees enlarge the total amount of more productive trees, therefore, the average yield of trees in this group tends to become much larger than the average yield of the older obsoleted capacity. Hence, trees which not long ago seemed to the farmer productive enough to warrant careful cultivation, will now appear as non efficient and costly trees to support. These trees will tend to be neglected and soon will pass to enlarge the normal flow of capacity being obsoleted.

The Obsolescence Multiplier adjusts the speed at which productive trees are obsoleted. Figure V-15 shows one possible relationship, among several others. When the yield ratio is closed to a normal value, say 2, obsolescence will proceed normally with the aging of the productive stock. As the yield ratio rises above the normal value, more trees become rapidly obsoleted.

The behavior of the World Coffee Production Sector with the addition of the two obsolescence loops (P6 and P7), is depicted in Figures V-16 a and b. In the first figure, the 30/15 year coffee cycles appear combined with higher frequency harmonics, as illustrated by the 'almost' square shape of the wave. More importantly, the price cycle seems to exhibit a larger amplitude, which means that the obsolescence mechanisms add instability to the main production loops.

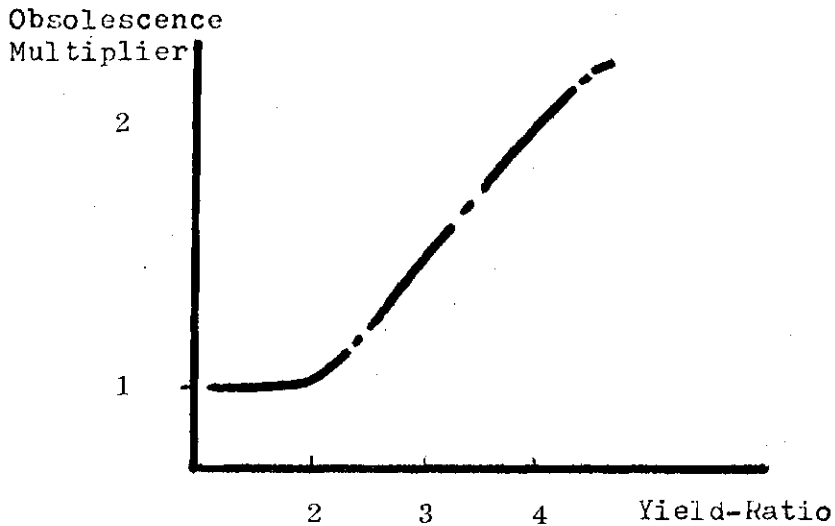


Figure V-15. Effect of Yield Ratio on Obsolescence Tree Rate

#### The Obsolescence Multiplier.

When world prices stay high for a long period of years, planting rates tend to be higher than removal rates. The stock of highly productive trees will tend to be too young, with lower but rising yields. Therefore, the yield-ratio will stay relatively low, as shown by Figure V-16-b right before 1940. Hence, tree obsolescence rate will be near its normal value, with very low induced obsolescence (loop P7). Over this period, production rates, although rising, will not be too high, a fact which supports a high level of prices.

On the other hand, the stock of young, rising yield trees will tend to become old enough at a certain age to reach high stable yields. Therefore, as this

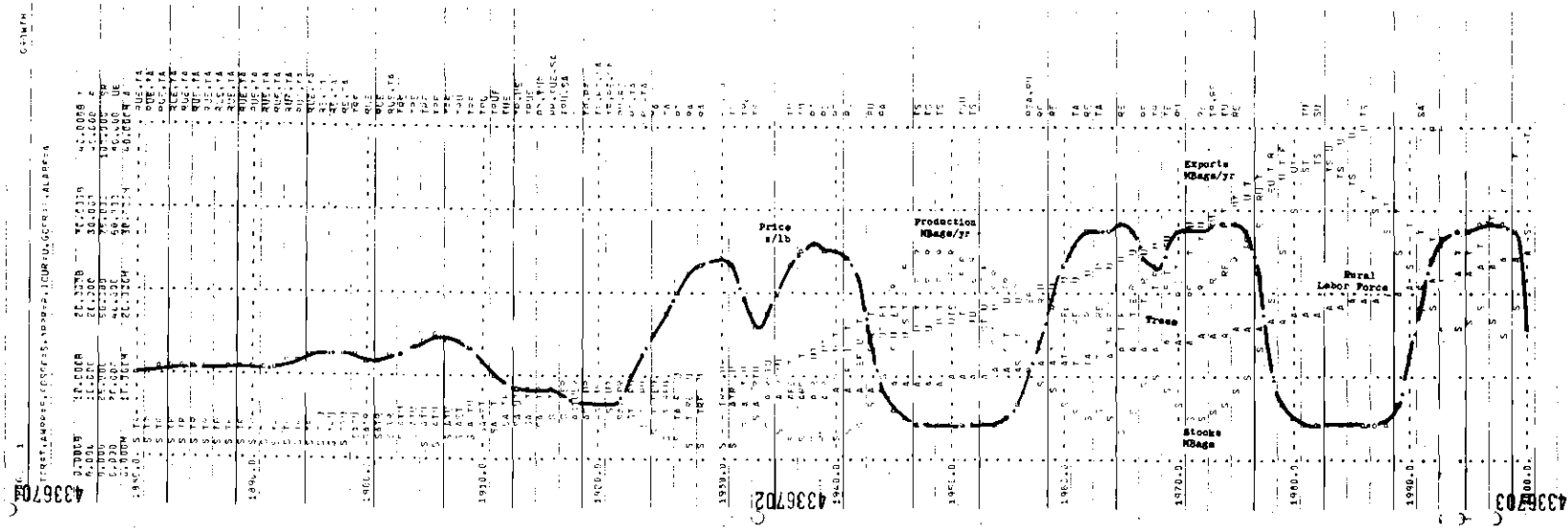


Figure V-16a. Effect of Obsolence (Loop P7).



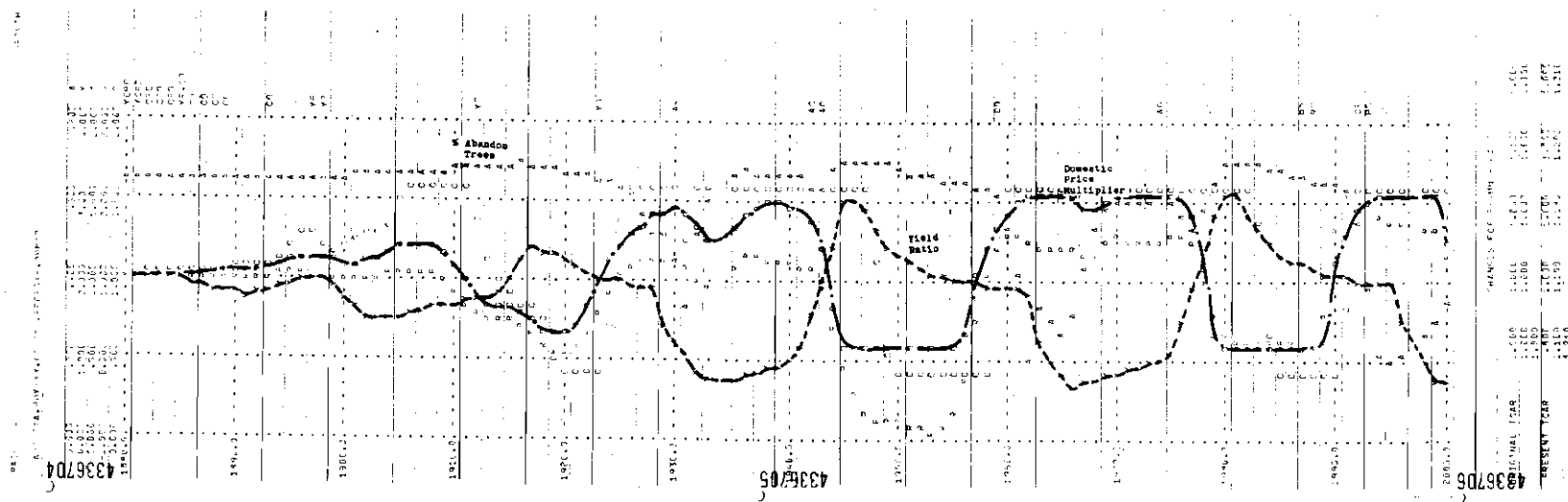


Figure V-16b. Effect of Obsolescence (Loop P7).

time approaches, the yield ratio tends to rise, as illustrated by Figure V-16-b, immediately after 1940. Furthermore, the sudden increase in the yield ratio induces a more rapid obsolescence rate (Loop Set P7), which means that the total stock of obsolete trees and the fraction of obsolete capacity will both grow. Hence, the farmer will plant additional trees (Loop P6) to replace those which were obsoleted and also to maintain his stock of more productive trees. Therefore, the stock of obsolete trees will look gradually younger because trees which were not too old were obsoleted much faster (Loop P7); similarly, the stock of highly productive trees will also tend to look younger, due to the rapid planting over the period (loop P6). Yields then will tend to be high; furthermore, the total stock of trees should be rising. This is the reason to explain both, the rapid growth in production rates and stocks, and the fast decay in prices when the yield ratio rises. See the two figures right after the year 1940.

When prices fall too fast, land expansion and planting rates are rapidly reduced. Therefore, the stock of highly productive trees tends to fall and also will tend to age faster which reduces the group's average yield. Hence, when this group of trees reaches, on the average, a certain age, the yield-ratio will tend to fall again, as shown by Figure V-16b after the year 1946. During these years, the total amount of trees stays on a plateau, and more importantly, the stock of trees is still relatively young. Therefore, the high number of trees combined with the high yields causes high levels of production rates and large accumulation of stocks. This is then, the reason to explain the sustained low level of prices since 1946 to 1954. During these years, a

reduced planting rate diminishes the stock of trees, which gradually ages to become older with lower and declining yields. Production rates and stocks will thus slowly fall. After a ten year period, production turns out to be lower than usage of green coffee. Prices then will recover.

d. Loop Set P8. Technological Innovations and Effective Yields:

Feedback Description.

(a) Technological and agricultural innovations in coffee tend to increase the average tree yield. Hence, production of green coffee stocks and then market supplies tend to rise over demand, which results in falling prices. With reduced prices, the depressed coffee foreign earnings of the nation(s) tends to hinder national development. Funds which were appropriated to agricultural research will be diverted to fit more urgent needs. Thus, technological innovations tend to stagnate for a period of time; the average yield of the coffee tree does not grow as fast as before (Figure V-17). The reader should note the long delays involved in the process of development and diffusion of technological advances.

(b) Similarly, as both world and domestic prices fall, the farmer will tend to shift the intensity of care provided to coffee trees in favor of other crops he generally produces as complementary sources of income.<sup>10</sup> Hence, the yield per tree tends to decay and production falls. Falling production rates produce a negative impact on both stocks and market supplies. Thus, prices

10)

The small farmer may actually provide more intensive care to the tree with the purpose of increasing sales and then income. There appears no evidence supporting this conclusion, however.

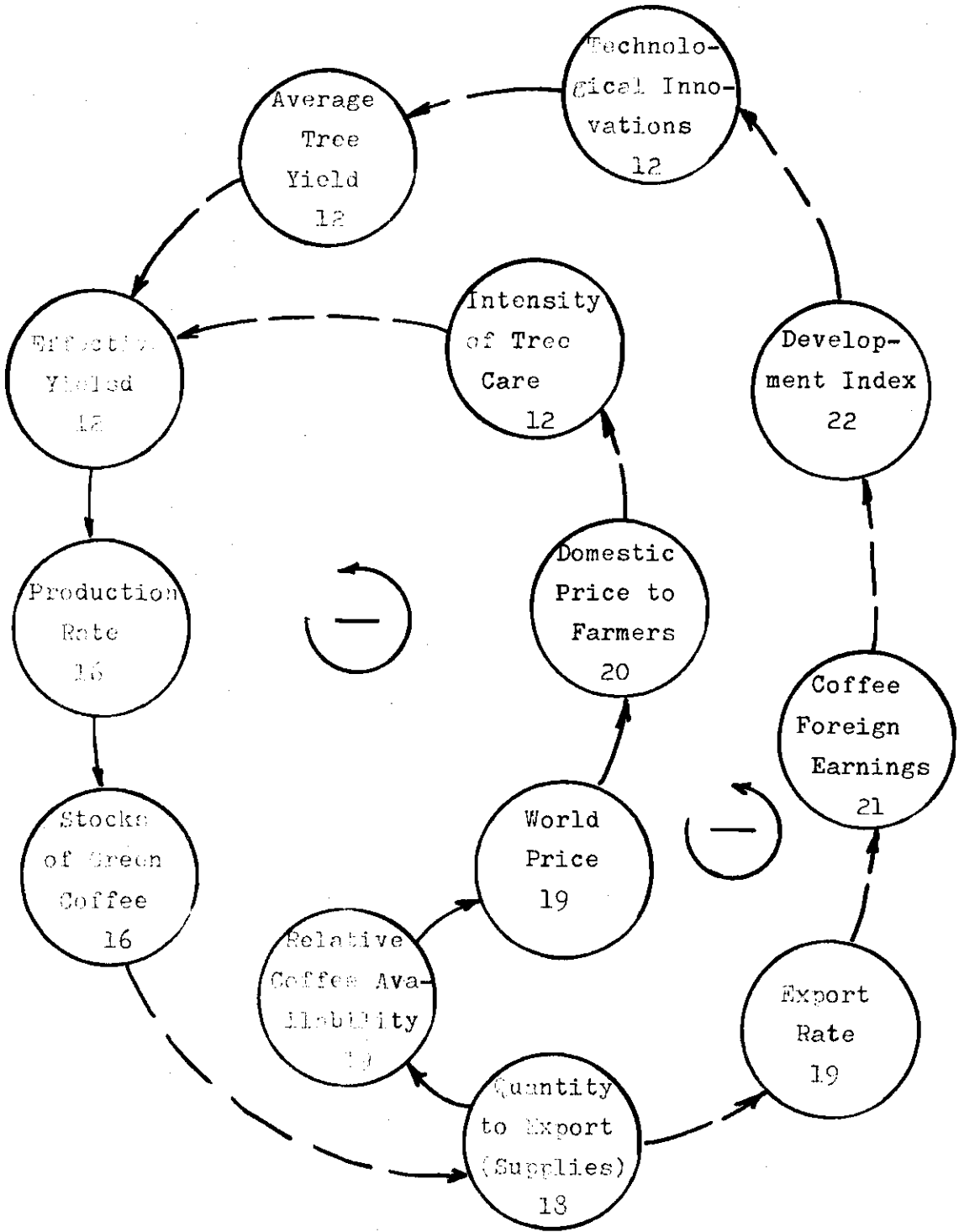


Figure V-17. Loop Set P8: Technological Innovations  
and Effective Yields.

tend to rise (Figure V-17). Effective yields are then given by the following expression:

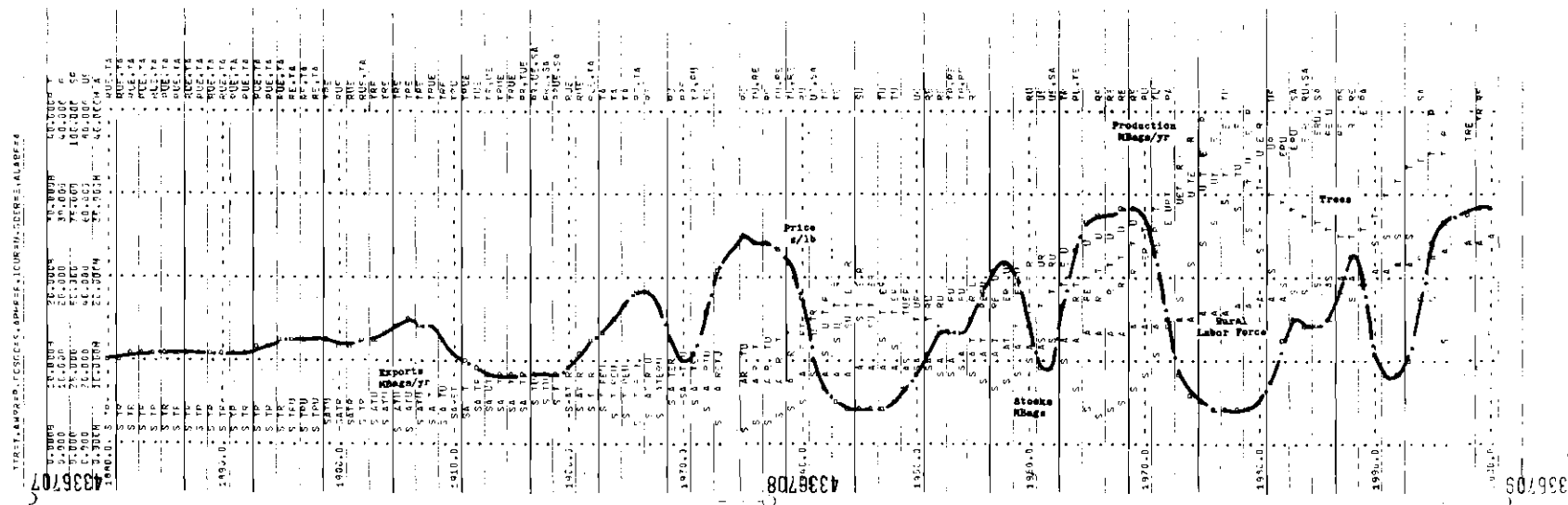
$$\text{Effective Yield} = \text{Average Yield} \times f_1 \text{ (technology)} \times f_2 \text{ (domestic price)}$$

where average yield depends on the age of the trees,  $f_1$  is the increasing effect due to advances in crop and seed technology and  $f_2$  is the result of varying intensity of tree care with prices.

The two following figures display the behavior of the World Coffee Production Sector under two different, but related situations. In the first diagram (Figure V-18), the main production sector (loops P1 to P4) has been simulated after addition of both the abandonment loop P5 and the effect of varying care on the coffee tree, as described by loop P8-b. In this run, the two obsolescence loops P6 and P7 have been omitted. The behavior still shows a major long movement of about 30 years, intermittent with high order harmonics of about 15 or 16 years and 8 years respectively. Figure V-12 showed the combined 30/15 year cycle generated by the interaction of the main production loops P1 to P4 together with the abandonment loop P5. Hence, the influence due to feedback loop P8-b, effective yields due to intensive care, is responsible for the appearance of a minor harmonic of about 8 years.

Figure V-19 shows the behavior displayed by the World Coffee Production Sector when all the feedback loops previously described are coupled together, i.e. Main loops P1 to P4, the abandonment loop P5, the two obsolescence loops P6 and P7, and the technological and effective yields loops P8-a and P8-b. Note the presence of the major cycle of about 30 years and the presence of several harmonics.





c. Loop P9--Foreign Cash Reserves and Suppliers Inventory Control

Policy: Feedback Description.

(1) Small Producers

Each small producing nation is unable to directly affect world price developments. A reduction in world coffee prices causes a diminishing flow of foreign earnings to the small producer nations; hence, cash foreign reserves tend to fall. To reestablish a poor cash position to a normal value, pressures develop to keep a lower amount of stocks, and then to export the excess to consumers. If all small producers behave in a similar manner, total world supplies at the marketplace will tend to rise, causing a further reduction in prices (Positive Loop in Figure V-20).

(2) Large Producers

A large producer, i.e. Brazil, is able to influence world price developments by controlling the amount supplied at the marketplace. Therefore, when prices fall, and the nation's foreign cash position deteriorates, the big producer will tend to keep higher levels of stocks, thereby, reducing the amount of supplies to the marketplace. Hence, total world supplies tend to fall, and prices tend to rise (Negative loop in Figure V-20).

The quantity of coffee to supply at the market place, depends on the average level of production, domestic needs and the difference between current stocks and the producer desired level of stocks.<sup>11)</sup>

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<sup>11)</sup> Producers will always keep a minimum level of stocks as protection against sudden price fluctuations and demand changes. This is explained in detail in Appendix B-II.



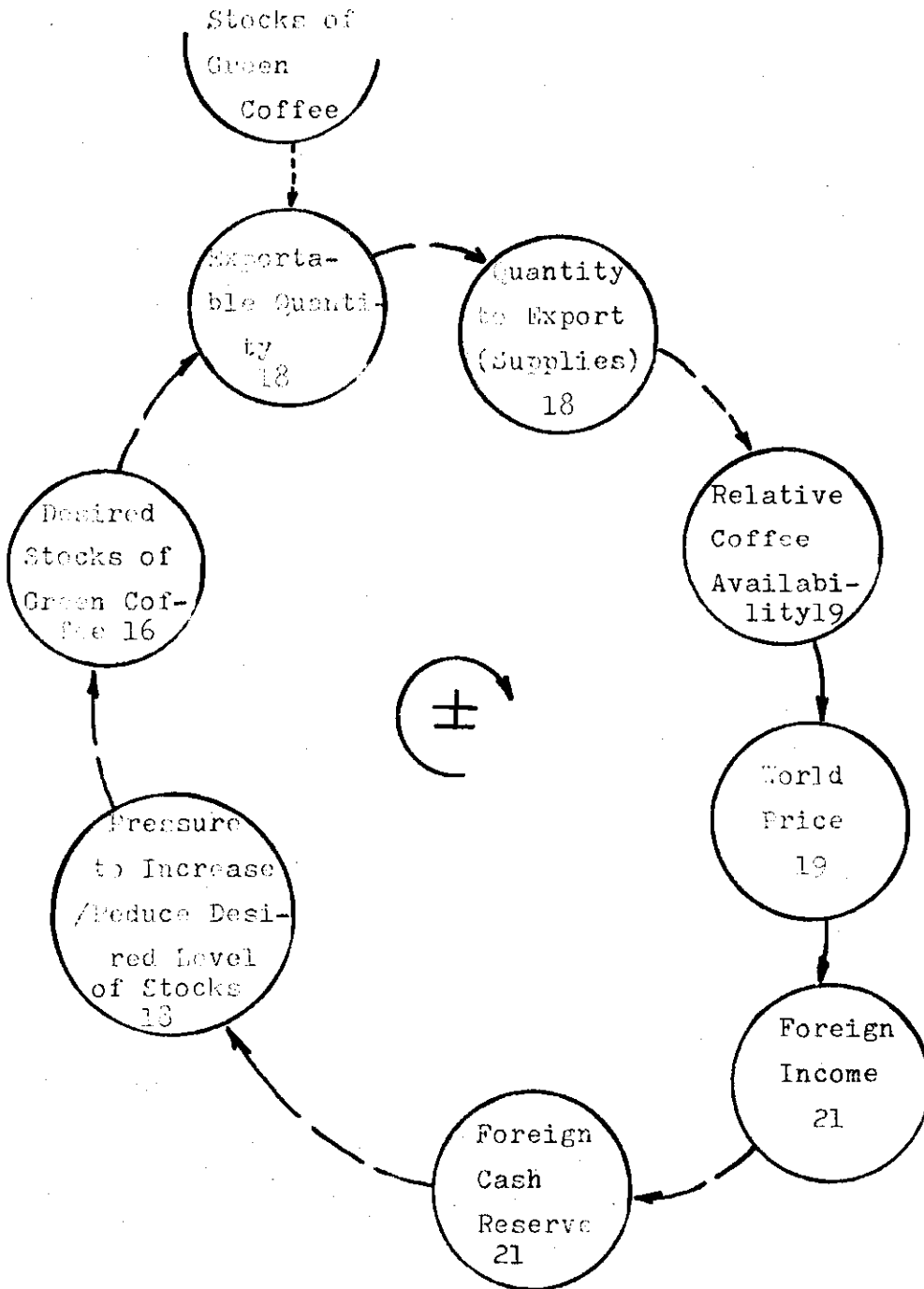


Figure V-20. Loop P9: Supplier Stock Control Policy.

Thus:

$$\text{Supplies} = \text{Production} - \text{Domestic Usage} + \frac{\text{Stocks} - \text{desired stocks}}{\text{PCT}}$$

where PCT is the number of months (years, etc) required to attain the inventory target value. Domestic usage is the amount of green coffee used by domestic processors; it depends on the producer nation(s) population and consumption per capita.

The desired level of stocks, depends in turn, on the nation foreign cash reserve. If the nation is a small producer, a low cash reserve causes a reduction in the desired level of stocks. Hence, supplies at the marketplace rise. If on the other hand, the nation is a large producer, a low cash reserve will induce retention of stocks and hence, a higher desired level of stocks. Figure V-21 displays these two types of relationships.<sup>12)</sup>

f. Loop P10--Export Quotas and ICA's Feedback Description. Falling prices induce nations to establish joint agreements to control the flow of supplies to the market. Upon signature of the agreement, a system of quota controls will prevail over a period of time, period during which the quantity supplied to the market falls to approach world demand. Hence, prices will tend to be maintained. If, on the other hand, market supplies become lower than world demand, prices will tend to recover and rise (Figure V-22).

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<sup>12)</sup> The basic model assumes a constant desired stock coverage (0.5 years of supply) for all producers. Chapter VII test the effects of each one of the relations depicted above.

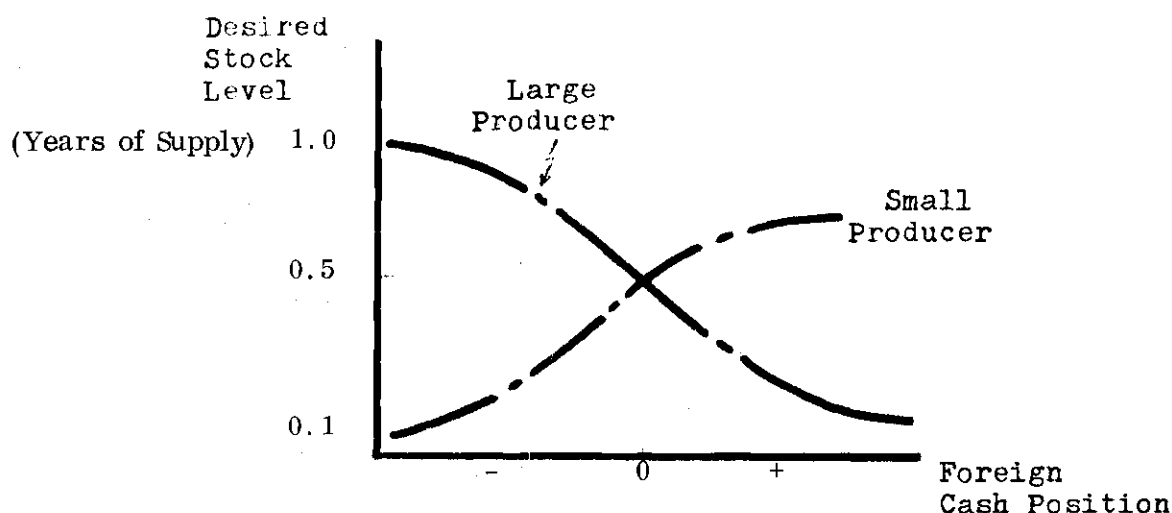


Figure V-21. Inventory Control Policy and Foreign Cash Position.

When the level of prices rise, producers gradually show less interest in supporting and enforcing the established export quotas. Controls are then relaxed, and thus, world supplies tend to rise again; therefore, world prices will tend to level off to fall later.<sup>13)</sup>

The effect on behavior of both the feedback which describes stock policy (loop P9) and the feedback which describes export quota policy (loop P10) is not given in this chapter. Their influence on behavior will be presented later, in Chapters VII and IX, respectively.

<sup>13)</sup> Destruction of stocks of green coffee has been a common practice followed by the large producers during periods of falling prices. This type of stock policy is described in detail in Appendix B-I.

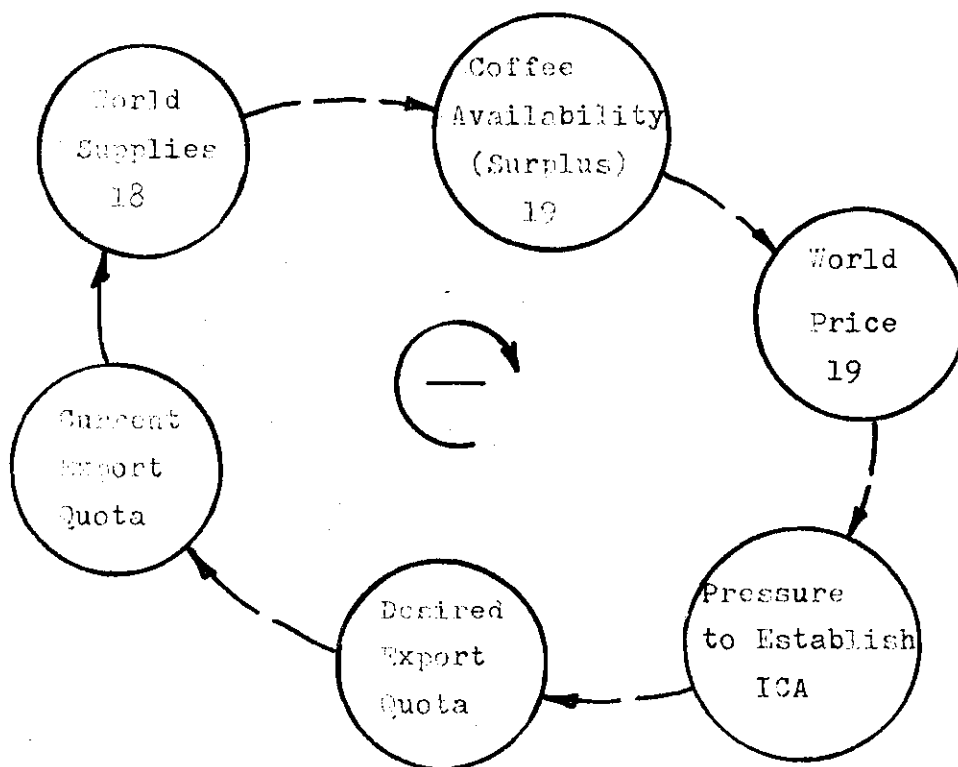


Figure V-22. Loop P10: Export Quotas and ICA's.

### C. Summary of World Coffee Production Sector and Behavior

This chapter describes ten major feedback structures within the World Coffee Production Sector. The behavior generated by the system presents clear evidence that a major cycle of about 'thirty-two' years plus harmonics, can be generated by the postulated feedback structure. In particular, this chapter has shown the following:

- (a) The main production loops (P1 to P4) generate a coffee cycle of about 30 years.
- (b) The abandonment loop (P5) causes a cyclic harmonic of about 15 years.

- (c) The efficient yield loop (P8-a) generates a harmonic of 8 years.
- (d) The obsolescence loops (P6 and P7) add higher frequency harmonics, and produce additional price instability.

The analysis of the coffee time series previously described in Chapter IV postulated a major coffee cycle of 32 years, combined with minor harmonics of around 16, 8, 4 and 2 years respectively. The results from the model compare very favorably with the main coffee cycles encountered in Chapter IV.

## CHAPTER VI

### THE COFFEE TRADE SECTOR AND THE SIX-YEAR CYCLE

#### MODEL STRUCTURE AND BEHAVIOR

This chapter presents evidence that a six year coffee cycle is generated by policies and practices originated in the coffee trade sector. The world coffee trade contains two major interlocked subsystems--the trade-distribution and the futures market subsectors (Figure VI-0). The chapter indicates, among other things, that the operation of the futures coffee market brings benefits to the trader who uses the market as a hedging device, in which case he may operate his business with a reduced amount of physical stocks. On the other hand, the chapter shows that the activity of the coffee futures market tends to add instability and wide oscillations to the six year cycle movements.

To some extent, this is a self contained chapter. The chapter briefly describes the operation of the futures markets, and shows the observed six year cycles in prices, stocks and volume of trade. In addition, the chapter postulates and describes the functioning of a feedback structure whose operation generates such market performance and presents the simulated behavior of this structure. Appendix BII describes each of the equations used to construct the trade and future market model postulated here.



## A. Physical Trade and Distribution Sector

### 1. Behavior of Traders

a. The Concept of Inventory Coverage. Time delays throughout the world coffee distribution system together with traders' anticipated expectations about future trends in prices create the need to carry inventories. A further reason to operate a business with additional levels of stocks is the frequent appearance of unpredictable events which cause wide price fluctuations as well as short term changes in the demand pattern. Conceptually, inventories can be segregated into at least four main categories, each of which supports different purposes. First, a working stock serves to maintain a continuous flow of business to the customer if supplies become temporarily short. Second, a safety stock protects the trader against the risk of stockouts due to sudden demand fluctuations. Third, price coverage and speculative stocks provide the trader with financial leverage against rising price trends, unexpected price upsurges or both. Finally, traders will normally want to keep additional strategic marketable stocks to enlarge the flexibility and strength of various penetration policies designed to increase the trader's market share.

Each one of the above four stock categories functions to provide protection to the trader in the face of uncertainty and delayed effects throughout the distribution system. The higher the levels of stocks, the higher the protection rendered by the inventory, but also, the larger the costs. A rational trader tends to weight the benefits afforded by the stock protection against his inventory holding costs. Therefore, the trader will tend to store coffee up to the point at



which the last unit of bought coffee barely adds benefits over the same unit's storage cost, that is, the marginal inventory holding cost equals the marginal benefit of the last unit added (Weymar [45, p. 35]).

The degree of protection a manager wants to afford for his business is represented by the inventory coverage. This is the period of time during which demand can be directly served from the stocks in case supplies become too short or too costly to buy. For instance, a half-quarter-supply of coverage means, that a trader may serve the normal customer demand during a period of a month and a half, should he not receive (green) coffee during that period. Therefore, an expression for the stock level is given by,

$$\text{Stock} = \text{Average demand} \cdot \text{coverage} \\ (\text{Bags}) \quad (\text{Bags/quarter}) \quad (\text{quarters})$$

and thus,

$$\text{Coverage} = \text{Stocks} / \text{Average Demand}.$$

As we will see shortly, the concept of inventory coverage is central to understand the behavior of traders in the commodity market.

b. Behavior of Coffee Prices and Coverage. Figure VI-1 displays the behavior of quarterly New York spot prices, together with the patterns of stocks and coverage held by U.S. roasters since 1954 to 1973. The price series exhibit two cycles of about seven and six years, price movements clearly defined by peaks during the years 1957, 1964 and 1970 respectively. This behavior

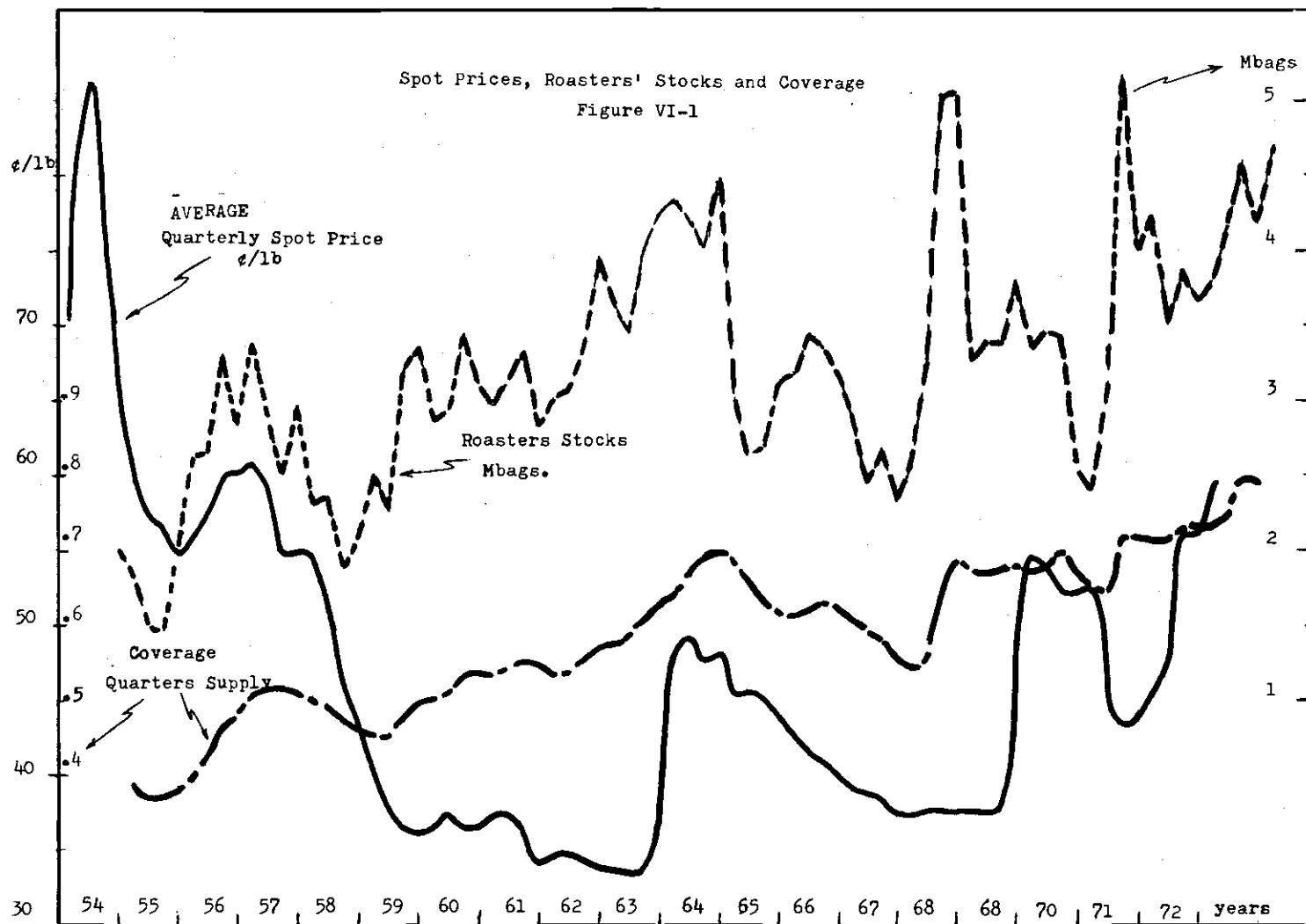


Figure VI-1. Spot Prices, Roasters' Stocks and Coverage.

appears, however, hidden within the pattern exhibited by the roasters' stocks where a cycle of about three years of duration is more apparent than one of six. Inventory coverage, on the other hand, exhibits two cycles of around six years each, cycles which closely follow the movements generated by the price pattern.<sup>1)</sup>

The behavioral pattern displayed by the inventory coverage admits at least two important observations. First, the pattern shows a secular trend beginning with a value of 0.4 during 1955 and ending with 0.8 quarters of supply during 1973. As the average coverage rises, the quarterly spot price seems to follow the downside portion of a longer term cycle: a 32 year cycle which began during the early fifties. In fact, if the reader plots a freehanded average on the price series, he will get rising spot prices at least since the earlier sixties. Thus, over the long run, both prices and coverage tend to rise together. A second observation results from direct comparison of the waves exhibited by prices and inventory coverage. Coverage peaks one or two quarters after prices have reached their maximum value, and more importantly, a rise or decline in prices is generally followed by a similar rise or decline in coverage. The above two observations suggest a close association between price and stock coverage. In fact, one could postulate that a positive price change (rising coffee prices)

---

<sup>1)</sup> Coverage has been calculated as the ratio of the U.S. roasters' stocks of green coffee to the average sales of roasted coffee in green coffee equivalent per quarter. The sales pattern shows steady growth, except for small peaks just before the winter season. Source: U.S. Department of Agriculture (U.S.D.A.)

induces a large coverage, and vice versa, a negative price change (declining prices) causes a lower stock coverage. This statement, when translated into managerial language, simply tells what is trivially known by roasters and traders; they will tend to increase their purchases of green coffee in anticipation of an expected rise in prices, but will keep hand-to-mouth stocks during periods of depressed and declining prices.

c. The Supply of Storage. The relationship between price change and coverage observed in the coffee market, is not a new concept. On the contrary, the concept is central to the theory of Supply of Storage, developed by several authors, Working (46), Brennan (36), Cootner (38) among others, and recently expanded by Weymar (45, p. 32) who successfully tested it on the world cocoa market. The theory relates expected price changes to the amount of stocks traders are willing to carry in order to protect themselves against adverse commodity market developments.<sup>2)</sup>

---

<sup>2)</sup> The amount of storage a trader wants to supply, that is, the level of stocks, is given by the amount of storage which equates marginal holding cost to the marginal benefit of carrying the stock. Thus,

$$MC_H = MB_{SS} + MB_{PF} + MB_{PT}$$

where

$MC_H$  is the Marginal Cost of Holding one unit of inventory.

$MB_{SS}$  is the Marginal Benefit provided by a Safety Stock, i.e. stockout yield.

$MB_{PF}$  is the Marginal Benefit provided by the Speculative Stocks.

(continued next page)

At negative rates of price change, when prices decay and supplies are abundant, a trader will always keep a minimum coverage, just enough to maintain the normal flow of business. As prices begin to rise, in the face of world-wide scarcity, traders gradually increase their coverage, thereby augmenting their purchases and stocks in anticipation of further price increases. On the other hand, if prices rise too fast, the additional cost to store the required stock tends to become abnormally high, fact which restrain the rapid expansion of coverage. Figure VI-2 shows graphically a supply of storage functions whose shape closely follows the previous discussion.

## 2. Feedback Structure of the World Coffee Trade and Distribution Sector

The feedback structure of the World Coffee Trade and Distribution System consists of two coupled feedback loops, one adjusts desired coverage in response to prices, the other adjusts current coverage to its target value.

Appendix B-II describes in detail the equations that compose the World Coffee Trade System.

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(continued)

$MB_{PT}$  is the Marginal Benefit provided by Price Trend Coverage Stock.

Thus,

$$MB_{PT} = \text{Expected Price Change} = \Delta P = MC_H - MB_{SS} - MB_{PF} = \Psi(c)$$

where  $MC_H$ ,  $MB_{SS}$ , and  $MB_{PF}$  are functions of coverage (c), in years-supply.

$\Delta P = \Psi(c)$  is the Supply of Storage function.

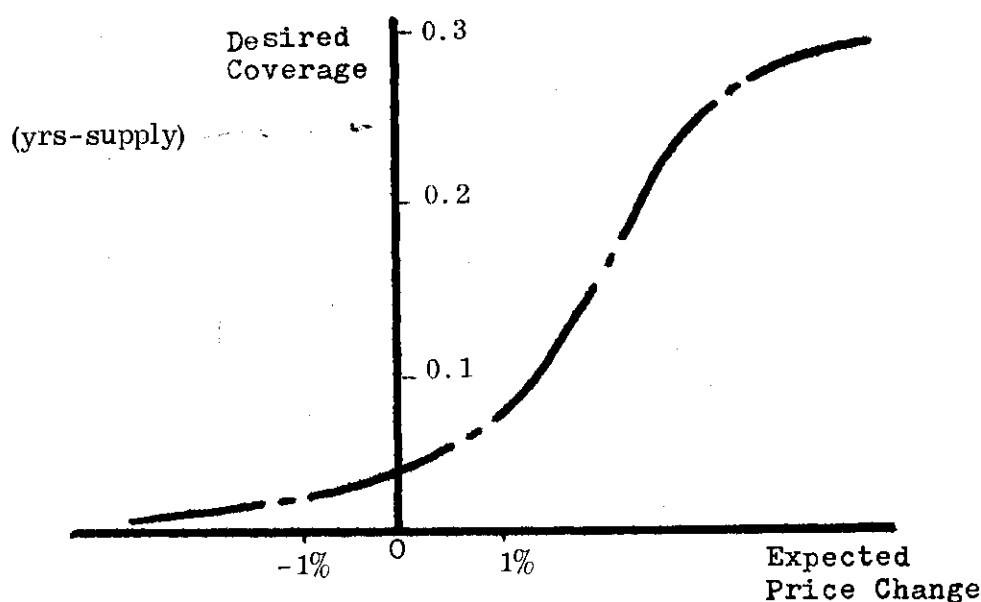


Figure VI-2. Supply of Storage Function<sup>(3)</sup>

#### a. Feedback Loops

##### Loop T1--Desired Stock Coverage and World Price, Feedback

Description. Rising prices in a bull market (positive price change) cause traders to augment their desired stock coverage. Desired coverage then, tends to rise above the current traders' coverage. To adjust current coverage to its new target value, traders will increase their demand for imported green coffee. Thus, supplies tend to become relatively more scarce and prices tend to rise faster. See Figure VI-3.

When prices are rising, change in price is positive. Traders, not knowing how far prices will increase and for how long, will tend to augment the length of their coverage period. (The Supply of Storage theory). Thus, to adjust

<sup>3)</sup>This is of the same shape as the supply of storage empirically developed by Weymar for the cocoa market [45, p. 64].

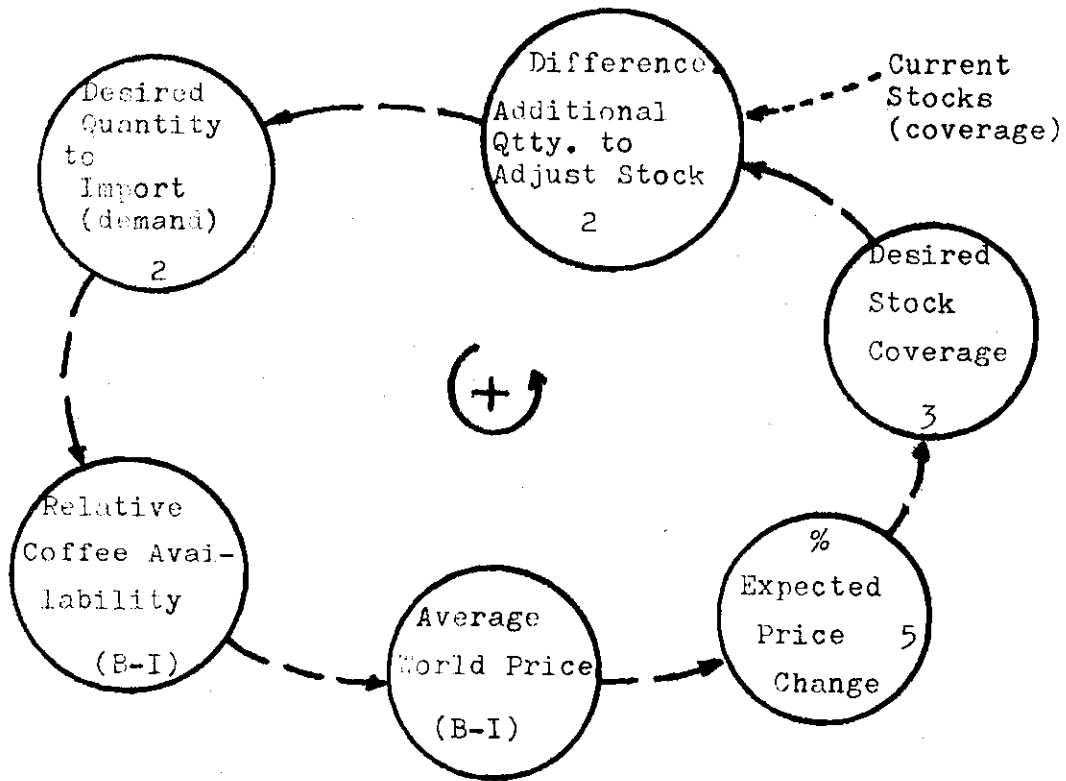


Figure VI-3. Loop T1.

the current coverage to its new target, additional amounts of green coffee will have to be purchased. If all traders respond to the rising prices in a similar way, total demand for green coffee (the Desired Quantity to be Imported) will grow too fast and above current world supplies. Coffee then, becomes scarce. In response to scarcity, each trader will tend to get their requirements at the expense of the other. Therefore, aggressive competition develops among the traders, who now will be willing to offer price premiums to avoid being under-supplied or driven out of business. Therefore spot world coffee prices will quote higher than initially; average prices then, will exhibit a rising trend

(Figure VI-3).

On the other hand, during a price fall when coverage decays, low traders' demand for green coffee, near or below current foreign supplies, will tend to shift aggressive competition from traders to producers. Therefore, suppliers will be willing to offer discounts to those traders who buy a certain portion of their stocks. Furthermore, as demand decays, the rising oversupply causes more aggressive competition among the producers who will offer increasing amounts of coffee at much lower price.

Figure VI-4 shows the effect of world coffee availability on prices. The curve may exhibit several possible shapes depending on how sensitive the market is to availability. The solid line may be in fact a plausible relation, as described more fully in the previous chapter.

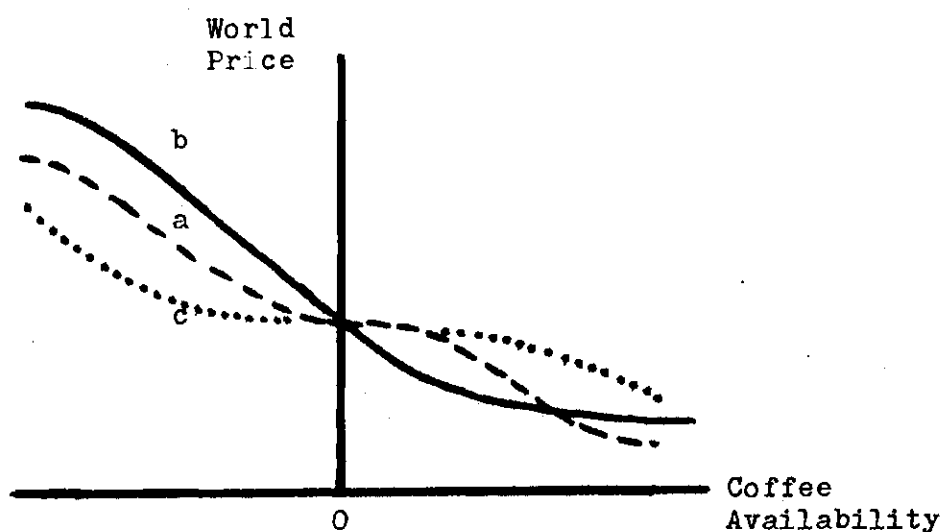


Figure VI-4. Coffee Availability and World Price.



Loop T2--Stocks and Replenishment Policy--Feedback Description.

Sales tend to deplete stocks, and hence reduce coverage. To restock low coverage, traders demand additional quantities of green coffee. After an elapsed period of time--the delivery delay--the purchased imported coffee will arrive to relieve the depletion and diminished coverage. Figure VI-5.

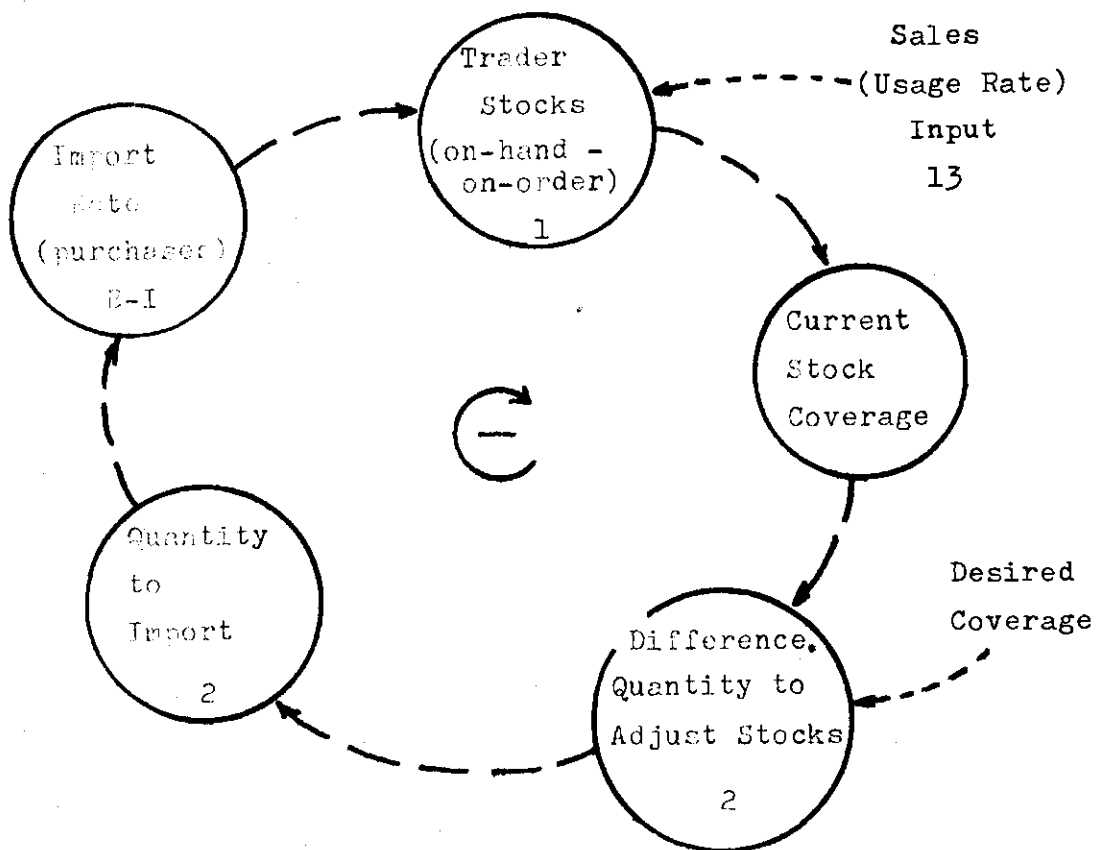


Figure VI-5. Loop T2.

When current stock coverage is too low or too high with respect to the desired coverage, traders will tend to adjust the desired amount of purchases so that stock coverage gradually approaches the target value. Thus, if sales remain constant, the desired volume of green coffee in inventories is given by the product between the desired coverage and the average sales. If in addition, the current volume of stocks happen to be equal to this target value, then each month the trader would have to buy an amount equal to his monthly sales to keep his stocks unchanged and hence, his coverage. If on the other hand, stocks are lower than the target volume, the trader would have to buy, in addition to the previous amount, a quantity of coffee sufficient to restore the balance: the difference between the desired level of stocks and the traders amount on hand. Conversely, if the level of stocks is higher than the target (desired) value, purchases will be reduced by the same difference.

The purchased quantity will not arrive immediately to the trader's warehouse; before arrival, the purchased coffee has to be ordered, packed, shipped, inspected and distributed. The total stock of coffee already exported, but not yet marketable, is coffee said to be in the pipeline. A trader who does not control his pipeline is bound to experience alternating periods of oversupply and shortage (Forrester [57, Ch. 15]). We assume that inventory control policies do include the pipeline. The effect of loop T2 is then, to maintain (total) stocks close enough to its desired level.

b. Behavior of Loops T1 and T2. Figure VI-6 shows the Feedback Structure of the trade and roaster sector. Figure VI-7 displays the behavior

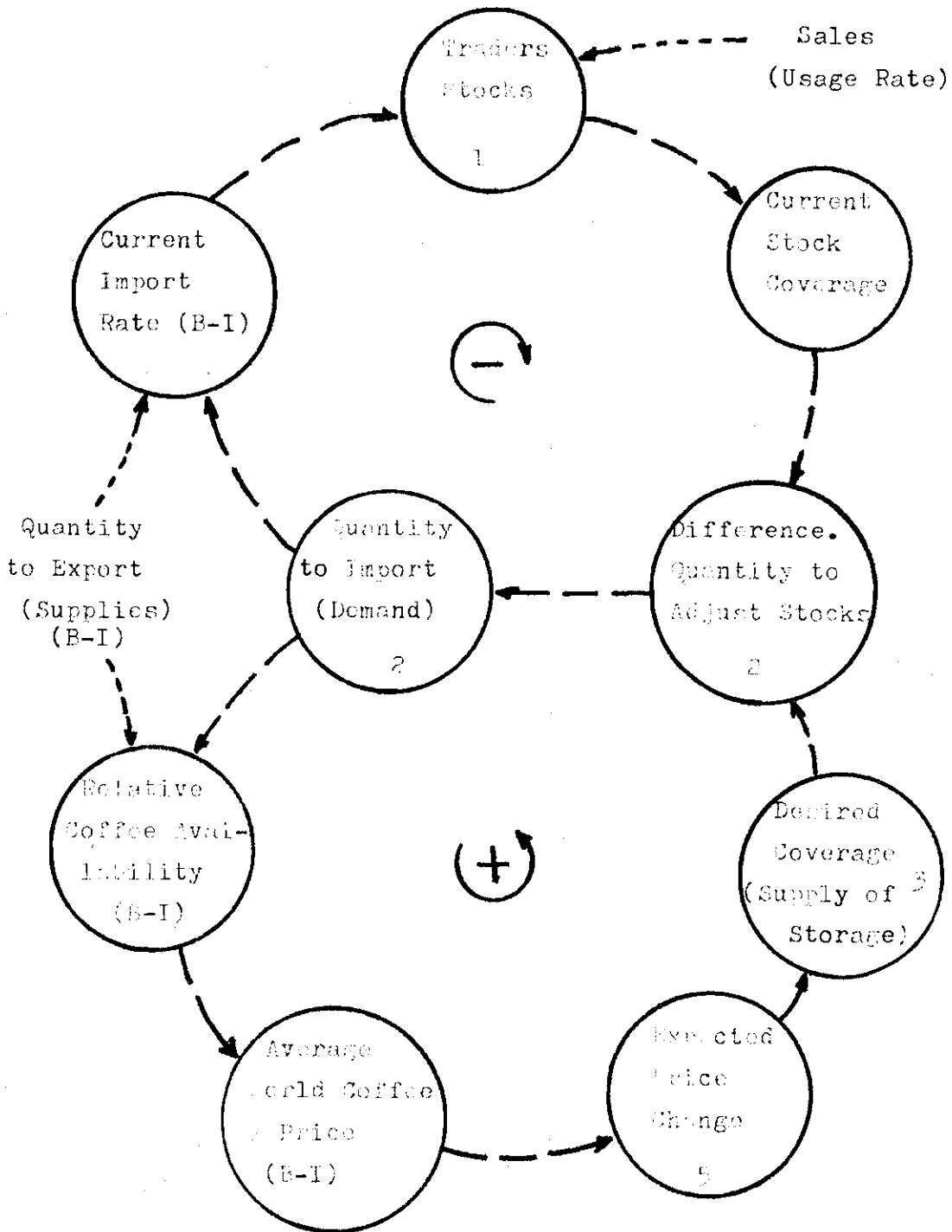


Figure VI-6. Trade and Roaster Sector Without Future Market.

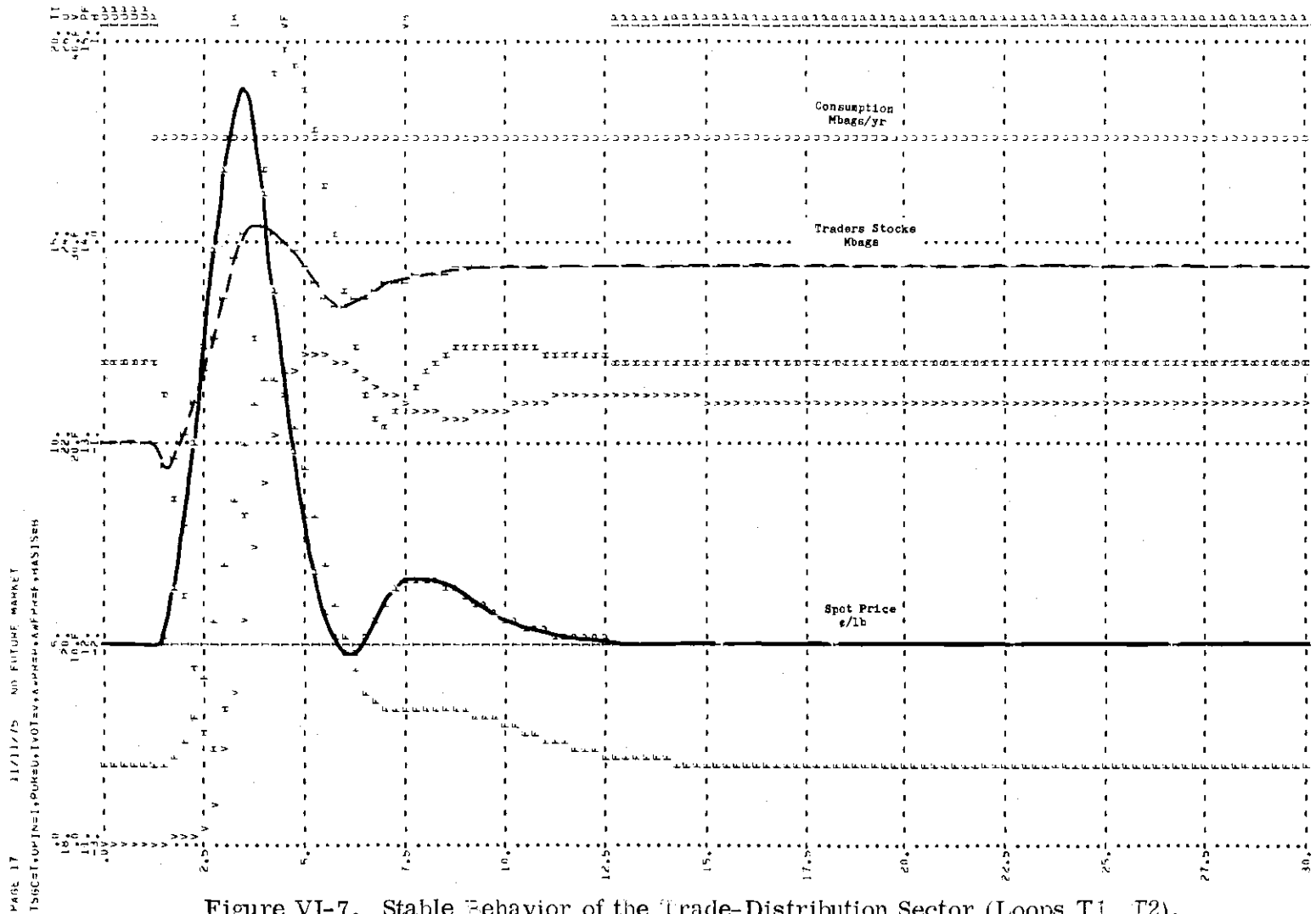


Figure VI-7. Stable Behavior of the Trade-Distribution Sector (Loops T1, T2).

generated by the two loops which compose this section. Initially, the system is at rest, that is, stocks and coverage are properly placed at their target values and the amount sold each year is equal to the amount bought each year. The run assumes that producer supplies stay constant, and are sufficient to satisfy traders requirements. After about 1.5 years, trader sales suddenly increase from 20 million bags per year to 25 million bags per year, and stay there during all the thirty years simulated.<sup>4)</sup>

The sudden rise in sales tends to deplete traders on-hand stocks, and reduce the year's supply of coverage below its target value. Therefore, traders will place larger orders for green coffee to restore both stocks and coverage. Prices then rise, so that traders will tend to increase their coverage (Loop T2); this effect creates higher demand on the suppliers and rapid further price increases.

After about one year, sizeable portions of coffee in the pipeline have already arrived into the traders' warehouses. Coverage rises and rapidly approaches the target (desired) value. Coffee demand on suppliers is then relieved and prices tend to fall. As prices fall, traders will tend to reduce their target coverage; Loop T2 now works in the opposite direction: reductions in desired coverage tend to restrain demand even more; hence prices and stocks

---

4) The amount of sales per year is an input to the system. In other words, internally generated changes in the model variables do not affect consumption of coffee. An input can take several forms, it could be exponential with growth, or random around a mean, or the well known step function, as used here. The use of a step input to disturb a dynamic model generally permits one to visualize with more clarity the behavior generated by the system. See Forrester [57, p. 38].

keep falling. In fact, prices decay up to the sixth year, year during which the depleted pipeline and stocks reduce the current coverage below their target value. At this time a new cycle is established.

A step-disturbance simulation shows that the behavior of Loops T1 and T2 is stable. The disturbance creates price and stock oscillations that tend to diminish with time. After year 15th the system is once again at steady state. The total amount of stocks, which initially was 5 million bags, becomes almost 15 million bags after the 15th year, because the coverage remains constant. (Constant coverage with higher sales implies higher stocks.)

The simulation run shows a price cycle of about 4.5 years of duration. This short cycle compared with the previous long price movements of 32 and 16 years, respectively, reflects the fact that the delays involved within the trade sector are much shorter than those within the production sector. Here, delays are of the order of one or less years of duration, as shown by the equations in Appendix B-II. The Trade-Distribution sector (Loops T1 and T2) form indeed a very stable structure. Changing parameters<sup>6)</sup> one-at-a-time or even three-at-a-time within a 50% change, do not suffice to cause instability.

## B. The Future Market

### 1. Background

This section briefly describes the terminology commonly used in futures markets operations. The following notes have been collected from bulletins,

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<sup>6)</sup> Parameters are values which remain constant throughout the simulation.

pamphlets and articles listed in the bibliography [18], [35], and [40].

Futures trade has informally existed since ancient times. During the last two centuries, futures trade has been formally organized in commodities exchanges. Nowadays, a trader can buy or sell contracts of coffee for future delivery in the New York Coffee and Sugar Exchange which established operations since 1882, or in the London Terminal Market, established during the nineteen fifties.

a. Futures Contract. A futures contract is an "agreement to buy and receive or to sell and deliver a commodity at a future date" [18, p. 46]. In coffee, a trader can buy or sell contracts to be delivered in the months of March, May, July, September or December. These contracts are generally called 'Marchs,' 'Mays,' etc.

b. Future Markets in Coffee. A futures market is a place where both buyers and sellers of future contracts meet to carry out their transactions at one commonly agreed price. This price is called the future-price.

c. Future-Price, Spot Price and Basis. Both futures and spot prices tend to follow similar trends. The difference between the two prices is called the basis. In most commodities, the basis generally exhibits smaller fluctuations than the two prices.

d. Purpose of Future Trading. Commodity prices exhibit fluctuations, and fluctuating prices create uncertainty and business risk. Holders of commodity stocks, that is, traders, dealers, roasters, processors, and even producers, generally called hedgers, require protection against adverse price

movements. At the same time, there are individuals who are willing to assume the risk of frequent price movements for the sake of profits. They are speculators who want to benefit from these price fluctuations.

Trading future contracts is a mechanism by which hedgers transfer the unwanted risk to the speculators. The following example serves to illustrate the process. Consider a roaster of green coffee, whose main business and source of profit is to supply the roasted coffee to several processors. Assume prices are rising and the basis remains the same. On July, he buys green coffee at 85¢/lb in the spot market, and simultaneously, he sells the same quantity of coffee in Septembers, at 87¢/lb. He then, earns 2¢/lb. One month later, he sells his roasted coffee at a price equivalent to 89¢/lb of green coffee, and buys a similar amount of Septembers at 91¢/lb, cancelling his previous commitment at the exchange. Then, he loses 2¢/lb, but in total he has ended even after completing the two transactions. During the initial transaction the roaster establishes a hedge; during the second he lifts his hedge.

The speculator, on the other hand, buys in July the Septembers sold by the roaster at the established 87¢/lb. Then, one month later, he will sell to the roaster the required futures at 91¢/lb, making a profit of 2¢/lb in his transaction. Thus, the hedger has shifted business risk to the speculator, who has been willing to absorb it if he thinks he can get a premium.

e. Volume of Trade. The total number of contracts sold and purchased in the exchange, over a period of time, is called the volume of trade.



$$\begin{aligned} \text{Volume of Trade} &= \Sigma \text{ Volume of Trade} \\ &\quad \text{Over all} \\ &\quad \text{Futures} \\ &\quad \text{Traded} \end{aligned}$$

$$= \Sigma \text{ Sales} = \Sigma \text{ purchases}$$

f. Short and Long Positions. Assume traders sell or buy futures which will mature during a certain month X. A trader in the X-future may have sold more contracts than he has purchased. Then, he owns a certain number of unliquidated contracts. Had the month of maturity arrived he will have to deliver a number of bags of coffee of a certain quality to a trader indicated by the exchange authority. If, on the other hand, the trader has sold as many contracts for the same future as he has purchased, then the trader is even. Finally, if the trader has purchased a larger number of contracts for the same future, than he has sold, then he owns the difference, as unliquidated contracts. Again, upon the month of maturity, he is obliged to accept on delivery the unliquidated portion of bags of coffee.

A trader who has sold more contracts than he has purchased is said to be 'short.' Conversely, if his purchases are greater than his sales, he is said to be 'long.' A trader who is even is in neither a long nor short position.

Thus,

if Sales > purchases, trader is short

if Sales = purchases, trader has no position

if Sales < purchases, trader is long

g. New Sales and Short Covering. A short who sells (new) contracts increases his short position. On the other hand, if he buys future contracts he is canceling a portion of his unliquidated contracts. Thus, if a short buys contracts he reduces his short position. This is the case of short covering (Figure VI-8).

h. New Buying and Long Liquidation. A long who buys (new) contracts increases his long position. On the other hand, if he sells some of his future contracts he is cancelling a portion of his unliquidated contracts. Thus, he reduces his long position. This is a case of long liquidation (Figure VI-8).

i. Open Interest. Open Interest is the total number of unliquidated contracts in the exchange market. The term is equivalent to open commitment or open position. It follows then,

$$\text{Open Interest} = \sum_{\text{all traders}} \text{Shorts} = \sum_{\text{all traders}} \text{Longs}$$

## 2. Behavior of the Coffee Futures Market

Whether the performance of futures markets is systematic or not is subject to question. Some authors claim that the existence of speculative markets precludes the presence of predictable components of price behavior. Within the length of tradeable contracts, any systematic behavior would attract enough speculation to iron out patterns with amplitudes greater than the burden imposed by brokers commissions and overhead (Working [46]). Opponents of this theory indicate that the commodity market is made not only by profit-oriented speculators

but also by hedgers (traders whose motivation is to diminish their operating risk). The effect of hedgers is then to transmit to the future market systematic movements originating in the physical distribution system. Supporters of this view note that the presence of predictable patterns results from the cyclic behavior exhibited by supply and demand and periodic limitations of storage (Hauthacker [39]).

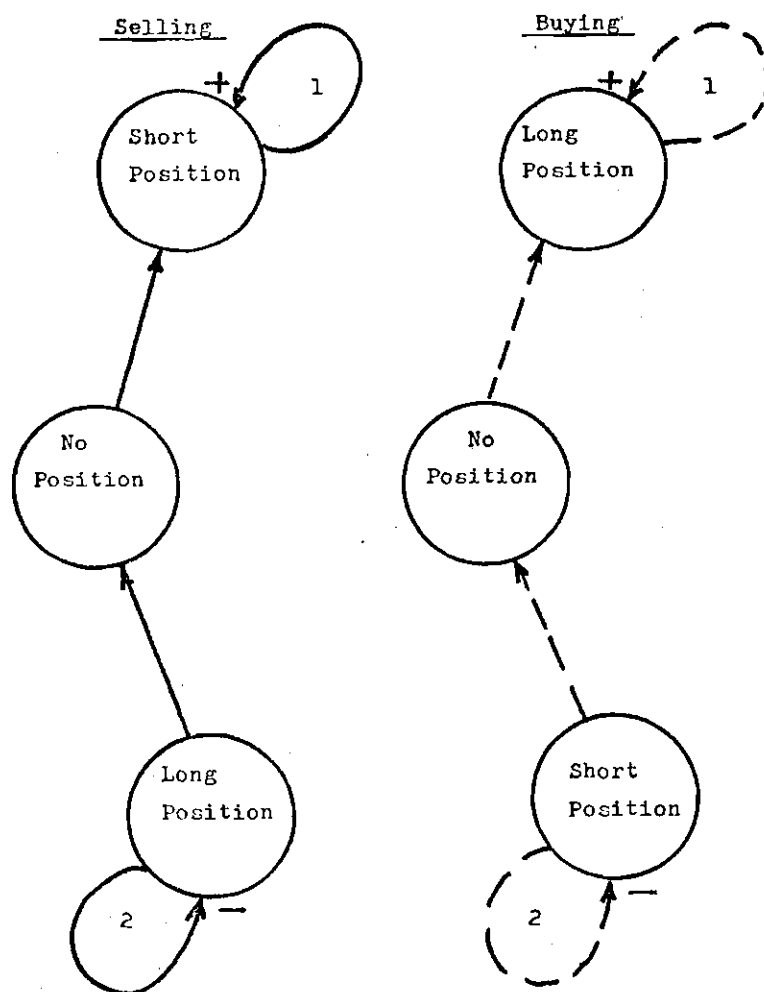
The presence of short-term futures price cyclic movements in U.S. domestic commodities has been confirmed by Hauthacker [39]), Smidt [44] Alexander [34] and Labey's and Granger [40]. These cycles are just strong enough to give a small profit to short term speculators. (See Appendix A, Literature Survey.)

The coffee futures market is dominated by hedgers (Gray [14]). This research takes the view that behavioral price patterns originates in the physical distribution sector of the coffee industry, passes to the futures market and reflects back onto the physical distribution sector. In fact, the research postulates that speculators, in the face of short-term random price fluctuations, are forced to liquidate their positions within a time too short to smooth out a coffee cycle of six years.

The future coffee market has traditionally been an inverted market. This means that the spot price tends to be most of the time above the quoted price for future contracts and also, that the current price of the nearest future tends to be higher than the quoted price of more distant futures. Gray [14, p. p. 303] reports that this situation has persisted during most part of the present

century. Figure VI-9 shows graphically the 'inverted' behavior of the coffee future market during a span of time sufficient to cover a full six year cycle.

The chart has been constructed from five quoted prices per year taken on or



1. A Short who sells is 'more' short  
A Long who buys is 'more' long

2. A Short who buys is 'less' short  
A Long who sells is 'less' long

Figure VI-8. Buying, Selling and Trader Position.

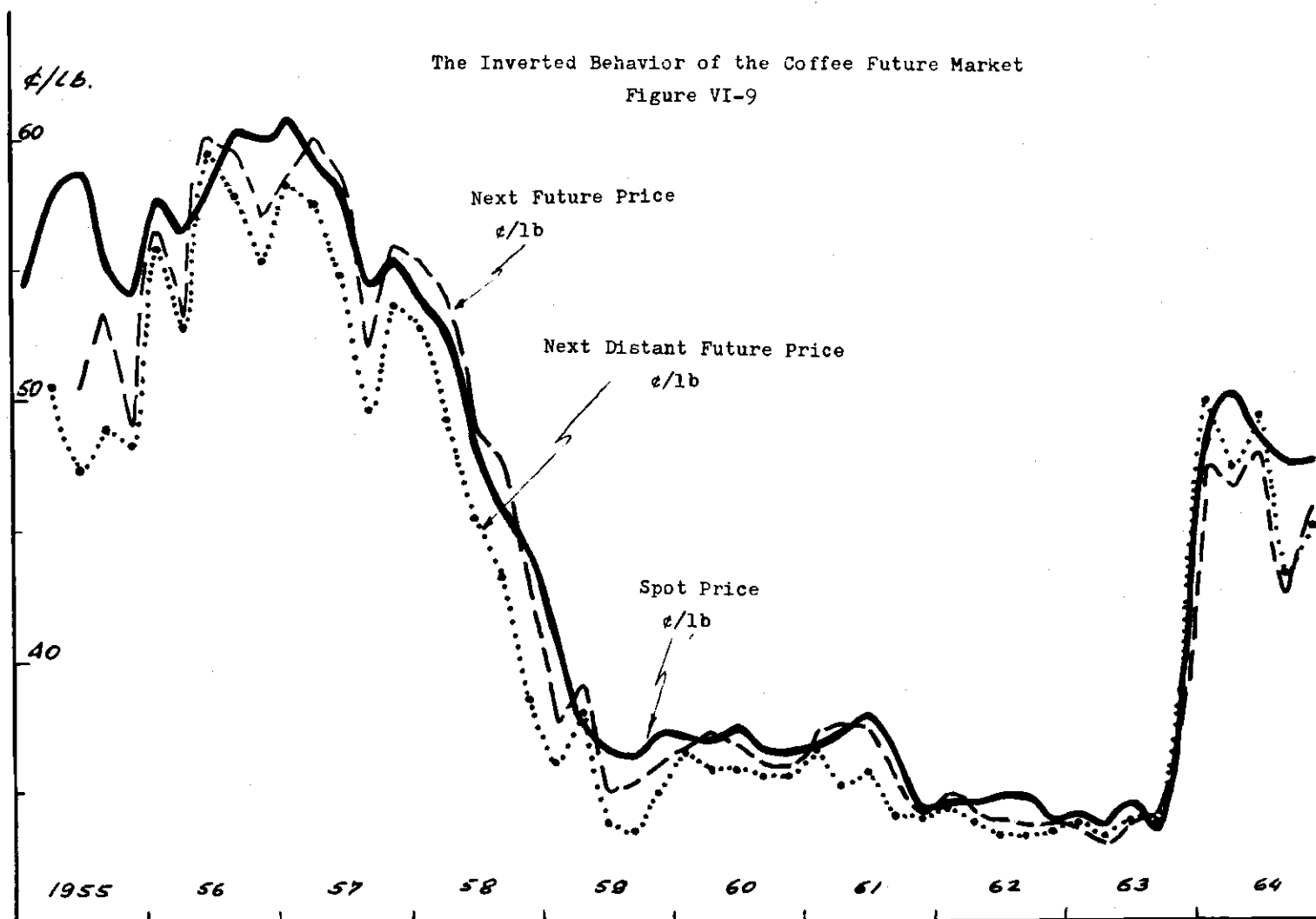


Figure VI-9. The Inverted Behavior of the Coffee Future Market.

about the twentieth day of February, April, June, August and November, in the New York Coffee and Sugar Exchange, respectively. The solid line reflects the spot price in the port of New York. The broken line shows the future price for the nearest future on the five dates and the dotted line shows the future price for the next distant future. For example, by the 20th of June of 1957, the spot price for coffee in New York was around 55¢/lb (solid line). On the same date, the price for coffee to be delivered on July (the next coming future) was 55.5¢/lb (broken line), while the price for coffee to be delivered in September (the next distant future) was 53.5¢/lb (dotted line). <sup>7)</sup>

In the same figure, the spread between the next and the next distant future narrows as prices rise and tend to widen during periods of declining prices. Furthermore, the fact that distant futures sell at a discount under the near future, has advantages for the trader who takes a long position; he will buy the distant future at the greater discount, and simultaneously will sell a previously bought nearest future at a higher price. Gray [14, p.304] found that the future coffee market has provided profits to traders who routinely take a long position; similarly he found a tendency of the coffee market to be biased against routine sellers, who generally end up with a loss if they keep their short position over a long period of time.

a. Speculation. Buying the discount seems to be a frequently used

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<sup>7)</sup> The chart has been prepared from data collected by Merrill, Lynch Associates and appearing in Coffee, a pamphlet.

technique in the coffee market. Such prestigious trading institutions as Merrill, Lynch and Associates openly suggest to speculators to maintain a long position in the more distant futures, Coffee [18]. In fact, the same trade firm claims to have published the benefits of this style of trading at least since 1950. Furthermore, the author found in personal conversation with an official of the firm, that this type of trading policy is normally used by professional speculators in coffee.

As said before the spread between the nearest and more distant coffee futures tends to narrow as prices rise, and tends to widen during a price fall. Hence, traders who buy the discount by routinely being long in the more distant future tend to get higher profits during a price decline, when the discount on the distant is higher. On the other hand, if one measures the spread as the difference between the distant-future price and the price of the nearest one, the result is generally, a negative number. Therefore, during a period of rising prices, when the basis (i. e., the spread) narrows, the percentile change in the basis turn out to be a positive number (See Figure VI-10). As prices fall, when the spread widens, the percentile change in basis is then negative. This means, that a positive change in basis, i. e. the discount narrows as price rises, tends to be associated with lower profits to the speculator; conversely, a negative change in basis, that is, the discount, widens as price falls, tending to bring higher profits to the trader.

Figure VI-11 depicts graphically the previous description. The figure

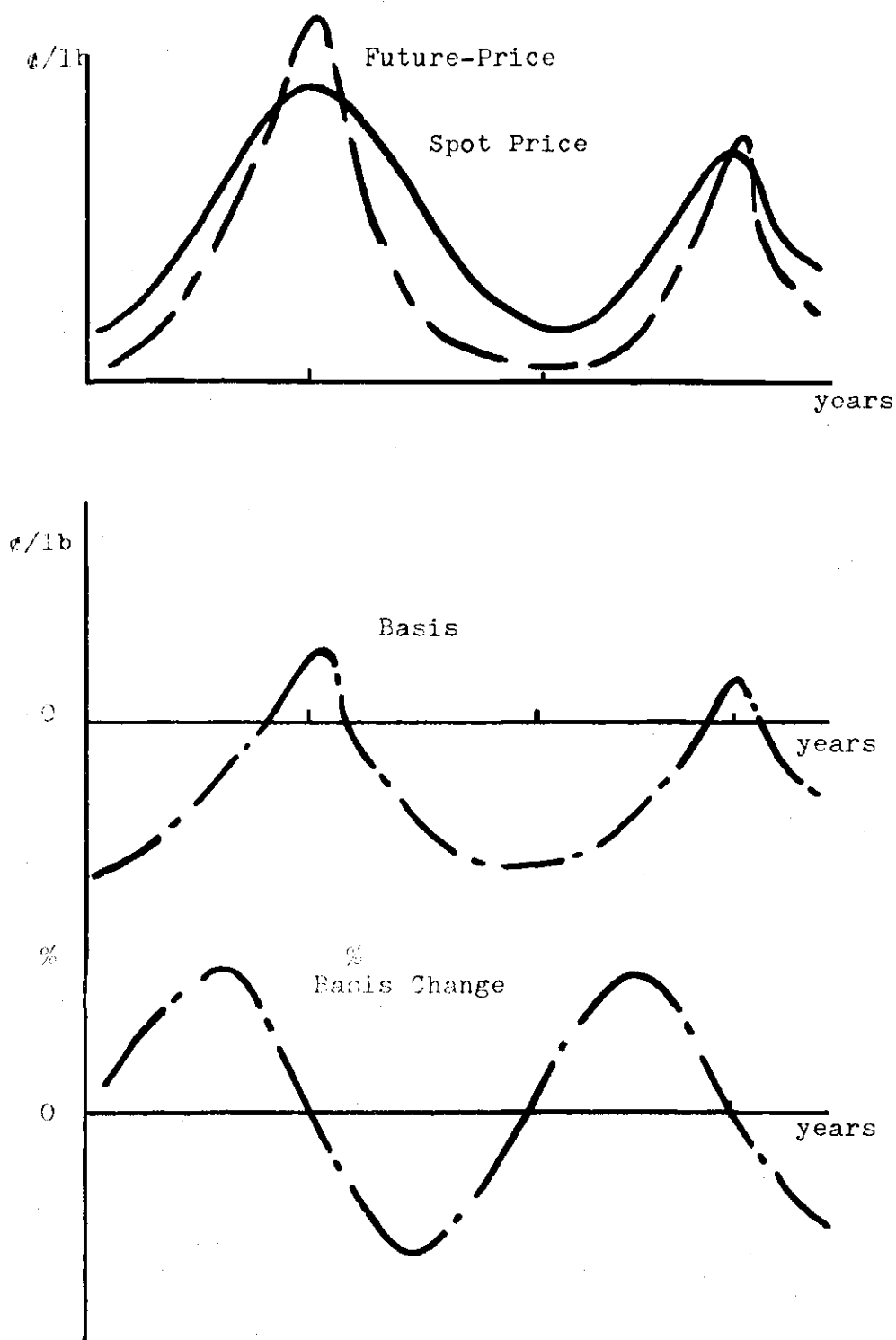


Figure VI-10. Behavior of the Inverted Future Coffee Market.



requires, however, a slightly different interpretation. A speculator expects to get higher or lower profits depending upon the way he thinks the basis is going to move; then he will tend to increase or decrease his desired long position on the future market accordingly. Thus far, the behavior of those traders who speculate on the spread could be expressed by the following statement:

$$\text{Desired Long Position} = \Phi_S (\text{Expected \% Basis Change})$$

where  $\Phi_S$  falls as the basis rises.

There are speculators in the coffee market who trade on 'price trends' rather than on spreads between distant and next-future prices. These speculators will prefer to maintain a long position as prices rise by buying distant which they will sell later, just before maturity, at the higher price. On the other hand, more professional speculators will tend to use a period with falling prices to establish a short position. They will sell a distant future at the higher price, and then, just before maturity they will buy the future to close their previous commitment. Therefore, at lower prices speculators on price-trend tend to increase their desired long position as prices rise; but will tend to switch to short positions if they expect a general fall in prices. Thus,

$$\text{Desired Long/Short Position} = F_S (\text{Expected \% Price Change})$$

The broken line in Figure VI-11 depicts this type of relation.

b. Hedging. Generally, a hedger in the coffee market is a holder of physical stocks who buys at the spot market and simultaneously sells distant

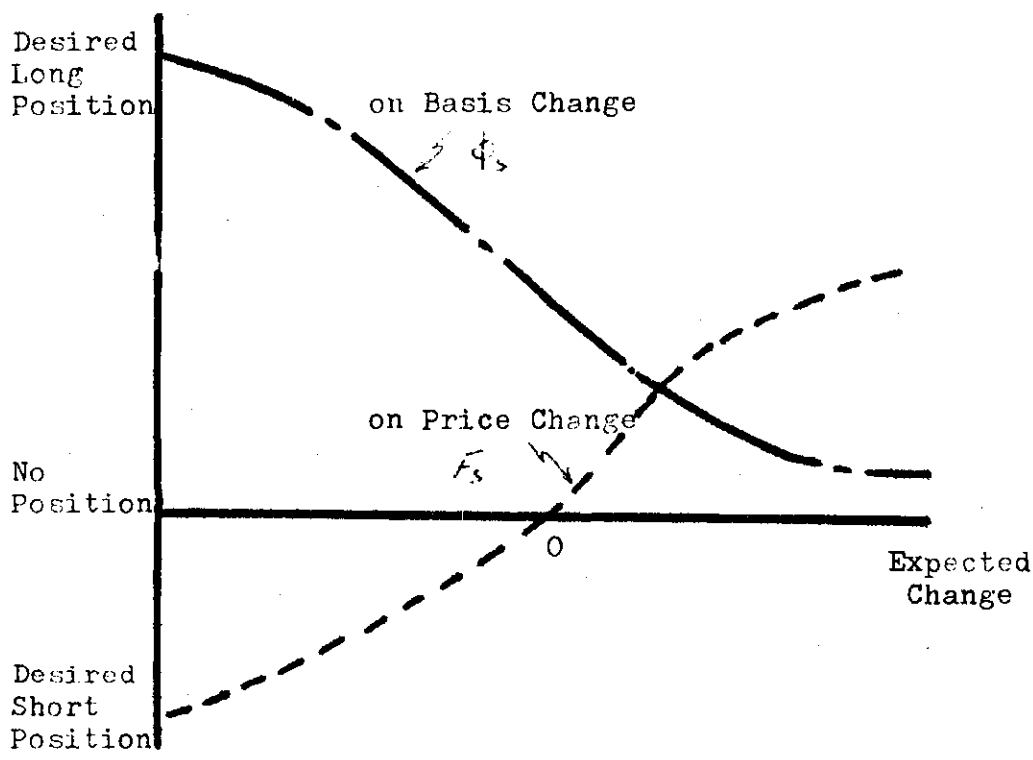


Figure VI-11. Speculators' Desired Position.

futures in the exchange, to protect his purchases against adverse price movements. Thus, he routinely maintains a short position in the future market.

Consider the following type of short hedge:

<u>Date</u>	<u>Spot Market</u>		<u>Future Market</u>	
July 10	Buy X pounds of green coffee at	$P_1 \text{ ¢/lb}$	Sell X pounds in Septembers at	$F_1 \text{ ¢/lb}$
Sept. 2	Sell to the customer X pounds of processed coffee at a price equivalent to	$P_2 \text{ ¢/lb}$	Buy X pounds in Septembers at	$F_2 \text{ ¢/lb}$
Profit/Loss in the transaction =		$(P_2 - P_1)$	+	$(F_1 - F_2)$

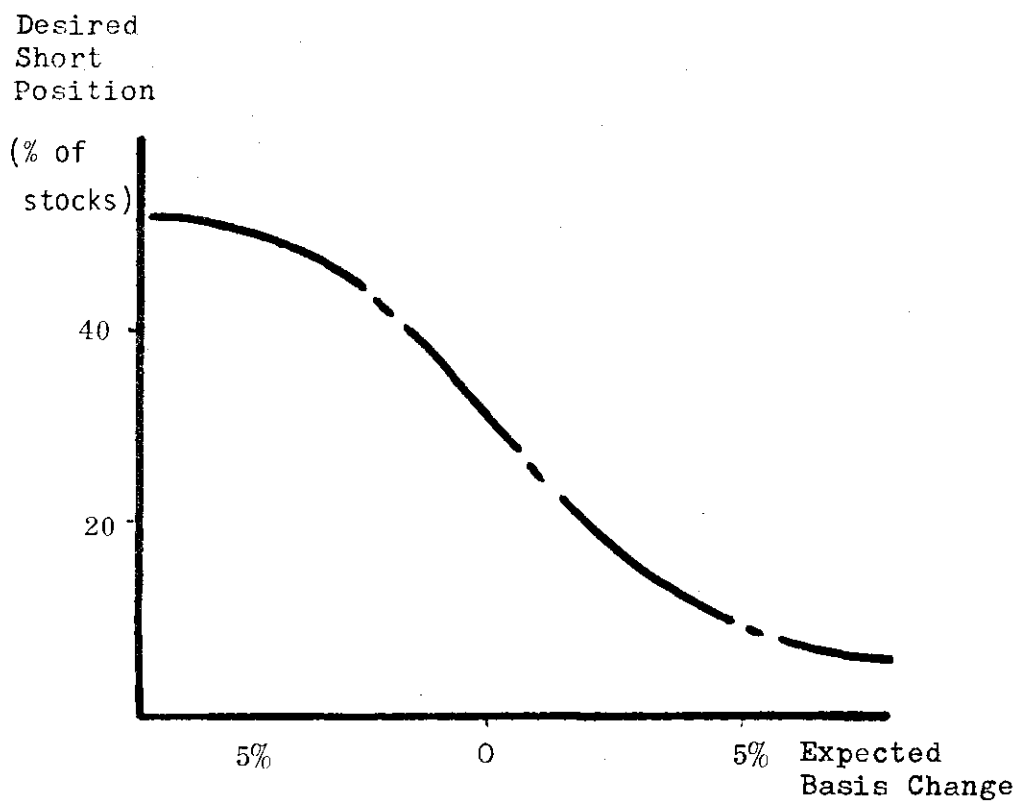


Figure VI-12. Hedgers Desired Short Position  
at a Given Level of Stocks.

$$\begin{aligned}
 &= (F_1 - P_1) - (F_2 - P_2) \\
 &= B_1 - B_2
 \end{aligned}$$

where  $B_1$  and  $B_2$  are the basis in July 10 and September 2 respectively. If  $B_1$  is greater than  $B_2$  the previous hedge provides a profit. As said before, the coffee market is normally 'inverted,' therefore both  $B_1$  and  $B_2$  have negative values, that is, spots are quoted higher than futures. Therefore, a profitable hedge is more likely to happen during a period of declining prices, when the basis is widening,  $B_1 > B_2$ . In fact, during this period, hedgers may prefer to sell distant over nexts, as it is during this phase of the price wave when distant exhibit the largest discount, a situation that tends to offer a wider margin of protection to the hedger.

When the basis narrows,  $B_2$  is less than  $B_1$  ( $B_2 < B_1$ ), the hedger loses money in his transaction. This situation tends to happen as prices rise, when the hedger is increasing his coverage and thus, his position in actuals. Hence, when the hedger expects the basis to narrow, he will tend to hedge a reduced fraction of his physical stocks; the hedger desired short position tends to fall. Therefore, hedgers' Desired Short Position can be formulated as,

$$\text{Desired Hedgers Short Position} = \text{Stocks} \times \Phi_H \text{ (Expected \% Basis Change)}$$

where  $\Phi_H$  appears depicted in Figure VI-12 for a given level of stocks.

### c. Volume of Trade and Open Interest in the Coffee Future Market.

Volume of trade is the total number of contracts purchased (and sold) over a period of time. Figure VI-13 shows the volume of trade in million of bags per

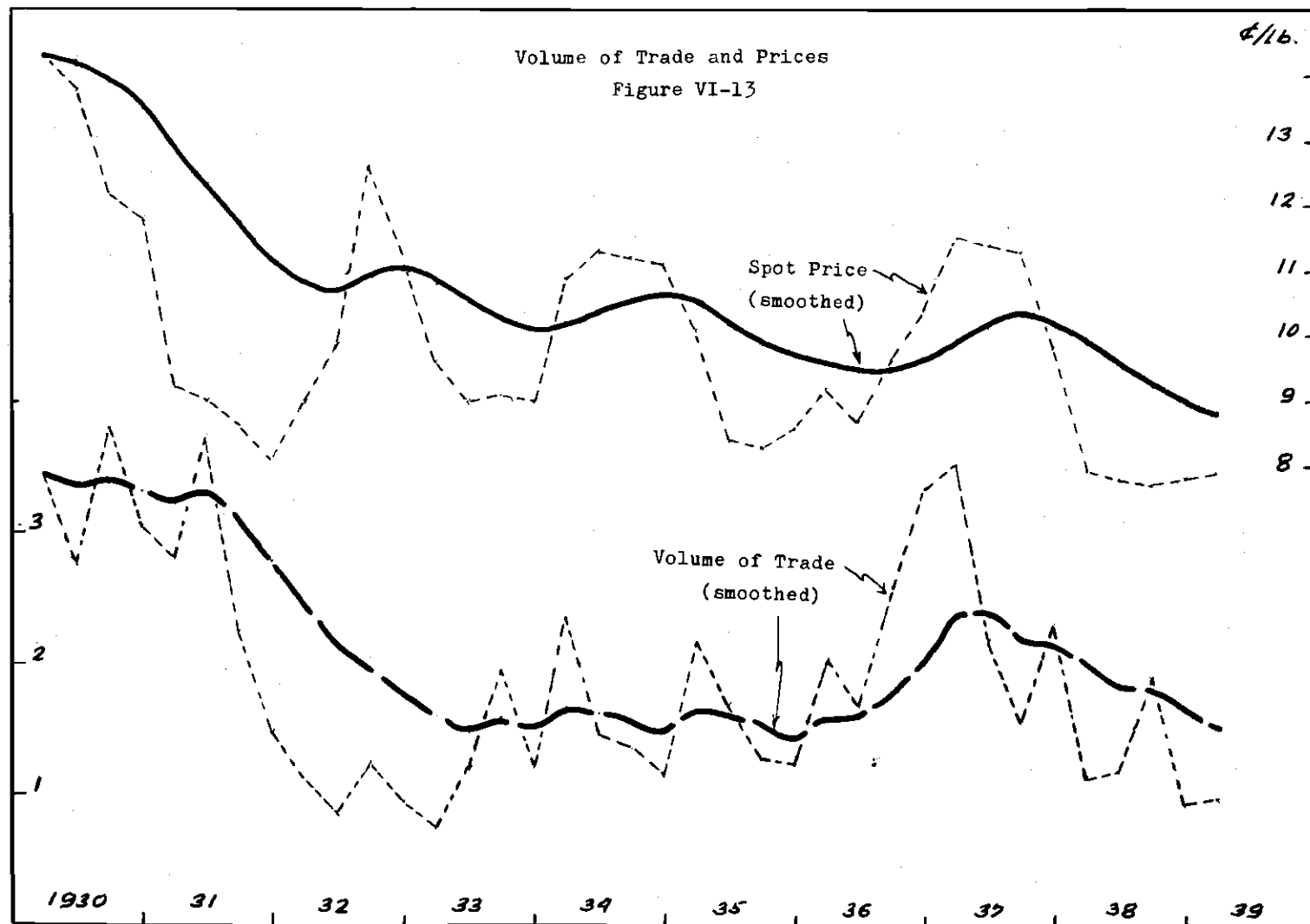


Figure VI-13. Volume of Trade and Prices.

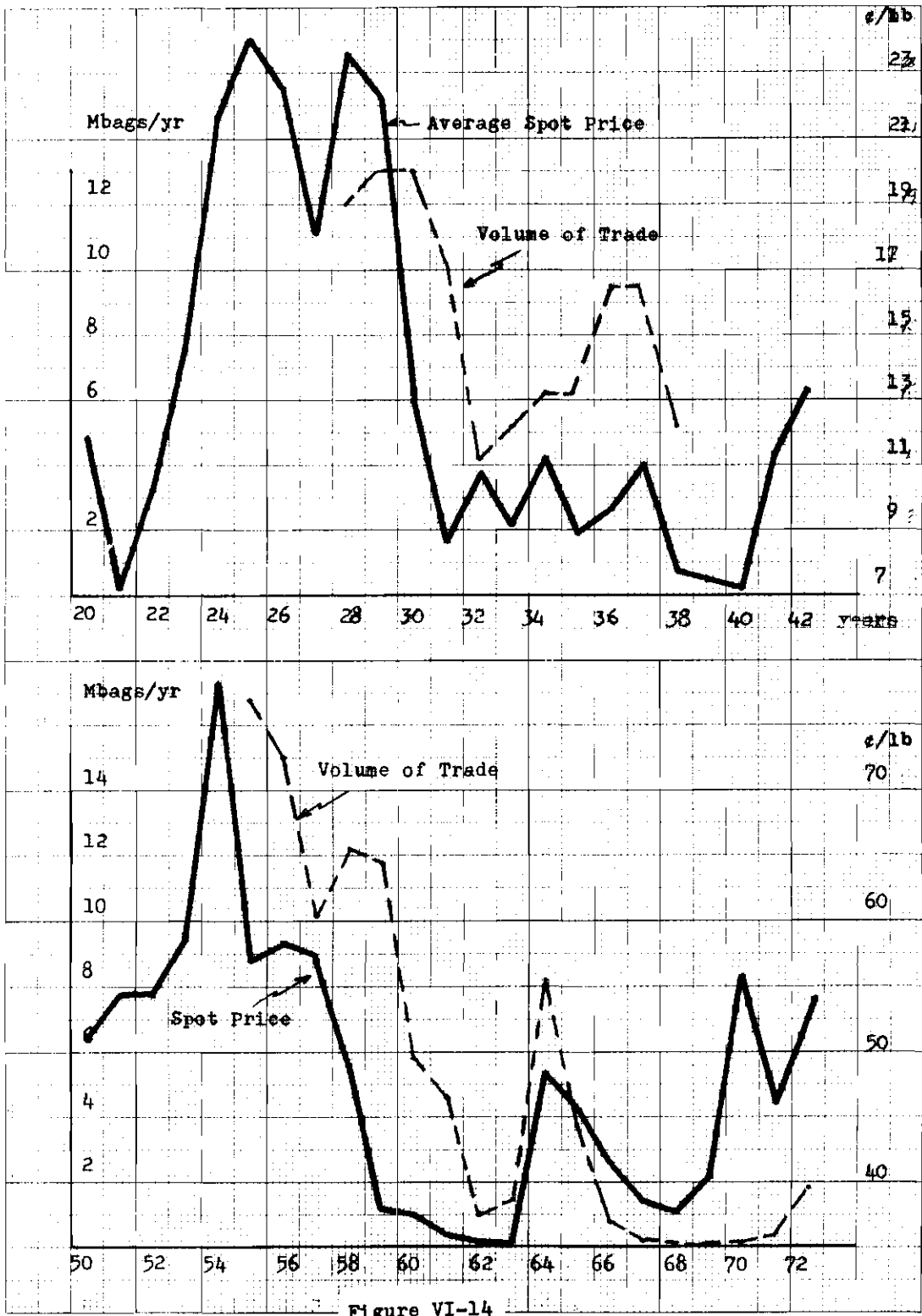


Figure VI-14. Volume of Trade.

quarter over the period 1930-1939. In turn, Figure VI-14 exhibits the annual volume of trade during the same span of time and also for the period 1955-1972. The solid line exhibits the behavior of spot prices in ¢/lb. In the two figures both volume of trade and prices display cycles of about six years, one from 1931 to 1937, the other from 1958 to 1964. More importantly, the smoothed curve showing volume of trade seems to follow the movements of the average spot prices.

The fact that volume of trade rises together with spot price, reflects the behavior of both hedgers and speculators. During a rise in prices, traders tend to increase their position in actuals, that is higher coverage; thereby they will more frequently use the futures market as a hedging device. In turn, as both demand for contracts and price rise, speculators become increasingly attracted toward the market, a fact which creates additional number of contracts traded, and a higher volume of trade.

In the United States, coffee is not regulated by the Commodity Exchange Authority (CEA), an institution which periodically reports Open Interest, Volume of Trade and several other statistics on most of the U.S. traded agricultural products. For this reason, among others, the author was unable to collect long run figures to describe the open commitment in the Coffee Exchange. Several coffee trading papers have reported the following characteristics of open interest in the coffee future market.

(a) Traditionally, a large percentage of the total open interest is composed of

open commitments in distant futures, Gray [14].

- (b) Open Interest was several times higher than physical visible U.S. stocks during the first decade of existence of the New York Coffee Exchange, which started operations in 1882. Thereafter, open interest in coffee has been much lower, and definitely lower than in most other commodities. The establishment of the so called Valorization scheme by Brazil in the early 1900s (a policy of stock retention), adversely influenced the speculators, who traditionally tend to trade in less restricted markets (Gear [13, p. 154]).
- (c) During the last thirty years, open interest figures have rarely been as high as the volume of stocks kept by U. S. roasters. This further reduction in open commitment may be contrasted with the establishment by producers of several types of International Coffee Agreements (ICAs) over the period.
- (d) The coffee market is a 'thin' market, mostly dominated by hedgers. The amount of speculation is low when compared with other markets, Gray [14].

From the above remarks it is difficult to draw conclusions about the behavior of open interest. In fact, as volume of trade rises, open interest may decay or rise depending upon hedgers and speculators' needs.

### 3. Feedback Structure of the Futures Market

#### a. Loop T3--Spot and Future World Coffee Prices, Feedback Description.

Rising spot prices generally cause rapid increases in the future price of the distant futures. In turn, higher future prices provoke additional rises in spot prices. Conversely, declining spot prices cause the distant future prices to decay, a fact which tends to accelerate a spot price fall (Figure VI-15).



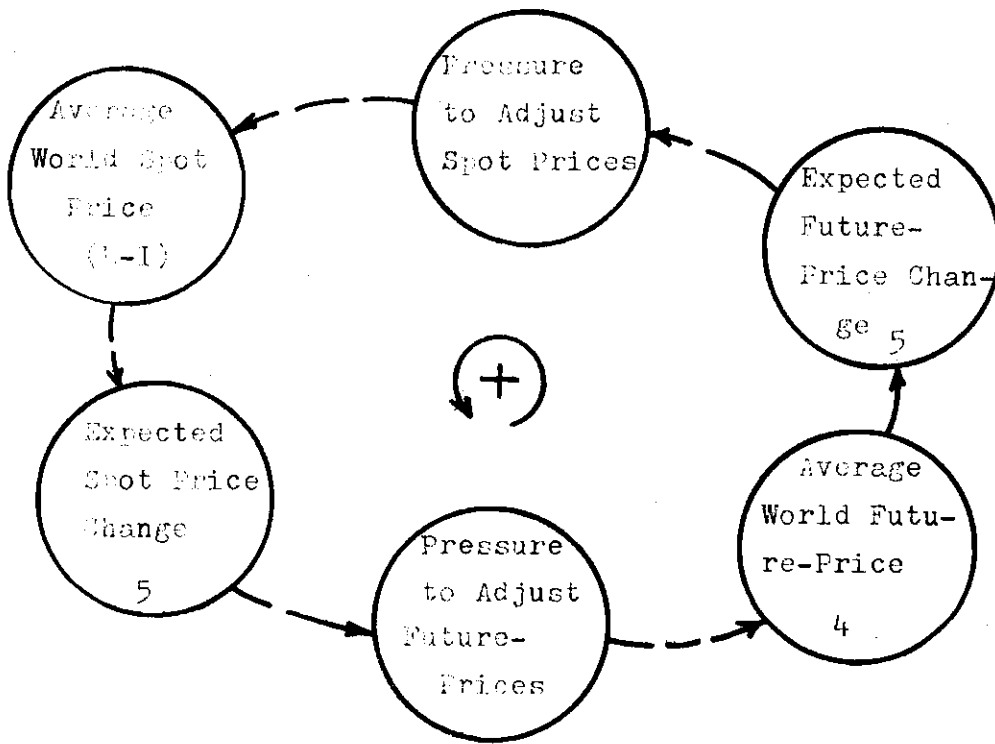


Figure VI-15. Loop T3: Spot and Future Price.

Both spot and future prices exhibit a similar six year cycle, as depicted by Figure VI-9. This behavior also appears in Figure VI-16, where the spot price has been plotted together with the highest monthly quotation for the (future) march contract, and over a longer period of time. The two figures clearly show that spot and future prices move together. In fact, futures prices tend to rise or decay a little faster than spot prices. Hence, an expected rise in spot price (positive price change) indicates to the traders that coffee is in short supply; speculators will tend to establish long positions well in advance, creating buying pressure on the future-price, which tends to increase. In turn, as future price rises (future-price change is positive), traders on actuals will tend to

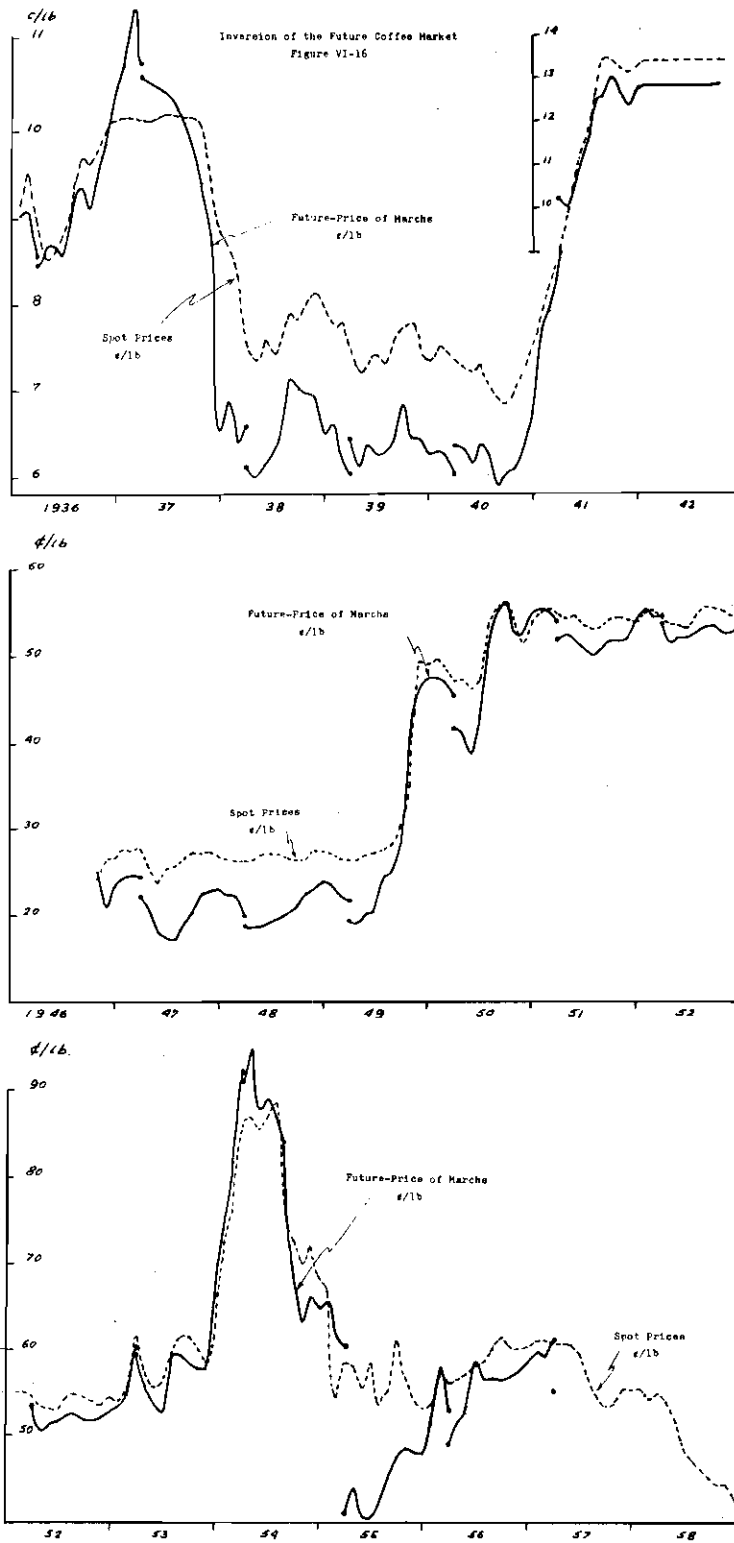


Figure VI-16. Inversion of March Future Prices.

confirm their expectations about the possibility of a coming period with short supplies. Spot prices then, will rise faster.<sup>8)</sup>

b. Loop Set T4--Aggressiveness of Buyers and Sellers of Futures and Future Price Formation, Feedback Description. Urgent short covering and rapid new buying rates reflect aggressiveness of buyers in the futures market. Similarly, prompt selling of new contracts and urgent long liquidation rates reflect the aggressiveness of sellers in the market. If buyers appear more aggressive than sellers, quoted prices will rise; otherwise they will tend to decline. Rising or declining future prices (together with 'basis' movements) causes traders to adjust their desired short or long positions to higher or lower levels of commitment. Comparison of the traders' current commitment, i.e. current open interest, with the established desired targets creates, in turn, the need to buy or sell more urgently, either by canceling previous (short/long) commitments, or buying or selling larger quantities of contracts to establish new (short/long) positions. Hence, if buyers are more active than sellers, prices will tend to rise faster, otherwise they will not rise as rapidly, or may instead fall (Figure VI-17).

Each desired short or long position in the aggregate coffee future market depends on both expected price trends and expected spread change,

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<sup>8)</sup> Several authors claim that a change in future price is a good estimator of a change in spot prices. See Labys and Granger [40, p. 89].

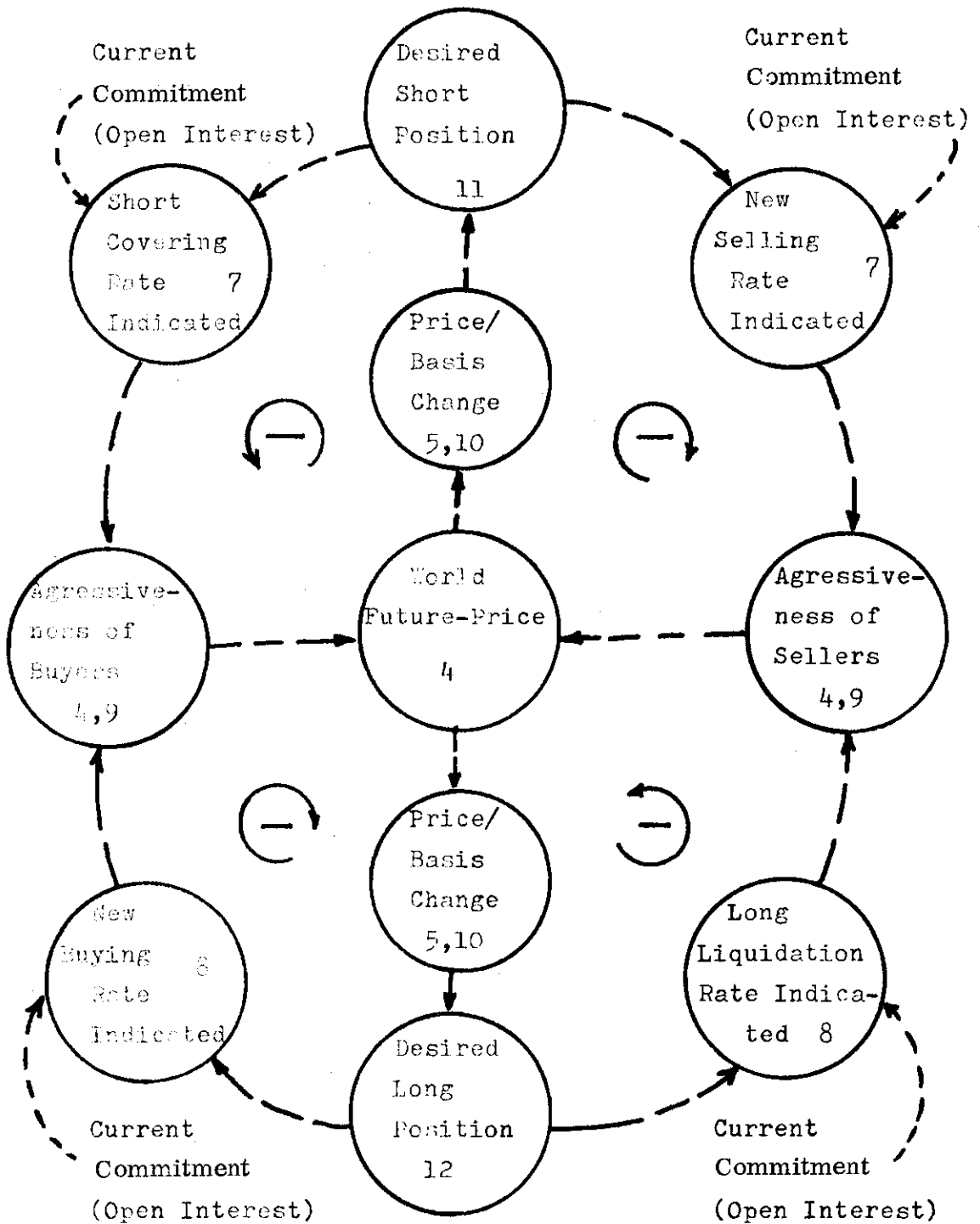


Figure VI-17. Loop Set T4: World Future-Price.

as depicted by Figures VI-11 and VI-12. In turn, the total current short position held by traders in the market is equal to the total long position held by speculators;<sup>9)</sup> each equals the total number of outstanding contracts in the futures market, i.e., Open Interest. If the desired short position rises above the current position by selling new contracts. Additionally, if for some reason, speculators expect prices (or spreads) to move adversely, to jeopardize their large long position, they will tend to sell and liquidate previously bought contracts, thus, reducing their net long commitment. Then, in both cases intended sales rise.

The two feedback loops to the left of Figure VI-17, describe the opposite effect. In this case, both, shorts and longs will tend to buy more contracts. If the total short position, i.e. open interest, is too high with respect to the shorts' desired position, traders will start buying back contracts to liquidate their excessive (short) position, hence, the short covering rate, i.e. purchases, tends to rise. On the other hand, if prices (or spreads) move to indicate favorable conditions to speculators, the desired long position tends to rise above the current long position; this is, above open interest. Hence, speculators will tend to buy new contracts to enlarge their current long commitments.

At the ongoing price, not all the intended sales (on purchases) will always be made. If intended sales is higher than intended purchases, sellers will

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<sup>9)</sup> The total number of contracts purchased should be equal to the total number of contracts sold. Thus, individually each trader holds a net short or long position, while on the aggregate,  $\Sigma$  shorts =  $\Sigma$  longs = Total Open Interest.

aggressively compete with each other and will offer discounts to prospective buyers. Hence future quoted prices tend to fall. If, on the other hand, buyers intend to purchase more contracts than sellers, they will offer premiums to those unwilling to sell future contracts at the old price. Hence, future quoted prices tend to rise (Figure VI-18).

c. Loops T5--Open Interest, Feedback Description. Selling and Buying new contracts augments the total market open interest, while short covering and long liquidation reduce the current open commitment. As open interest rises above the desired short and long positions, old open contracts are canceled. Hence, as short covering and long liquidation rates augment open interest gradually falls to approach from above, either the desired short or long positions, or both. A low value of open interest, below one of the target (desired) value(s) has the opposite effect. New buying or selling rates will tend to rise, adding more open contracts to the market, hence increasing the open interest which gradually will approach, from below, the established target(s) (Figure VI-19).

d. Loop Set T6--Desired Short Position and Degree of Protection Afforded by the Volume of Stocks Hedged in the Future Market, Feedback Description. Larger quantities of physical stocks requires frequent use of hedging as a protective device in the futures market. Thus, stocks and open (short) commitments tend to rise together. On the other hand, the higher the open interest (open commitment), the higher the degree of protection rendered by the future market and the less the required coverage (years supply) in

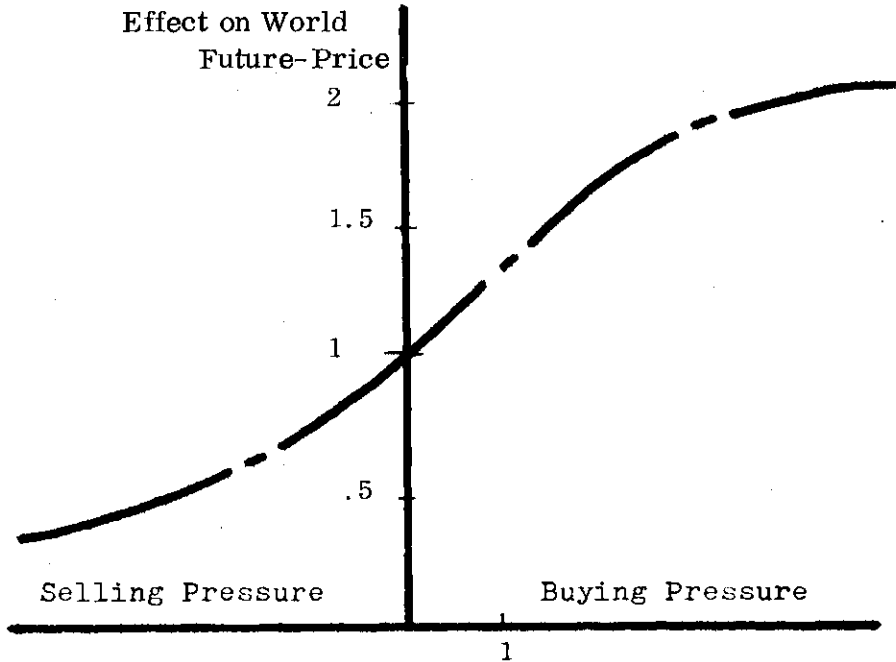


Figure VI-18. Future Price and Aggressiveness of Buyers and Sellers.

physical stocks. In turn, as desired coverage falls, the quantity desired to import (demand) tends to decline; stocks and prices then, will tend to fall.

If stocks decay faster than prices, traders will be able to operate with smaller short position. Hence, they will tend to liquidate old open contracts, which means that open interest tends to decrease toward a lower level of commitment (Loop T6-a (VI-20). Nevertheless, if prices fall faster than stocks, the effect of a widening basis tends to force traders to keep a larger short position (Figure IV-12). Hence they will sell new contracts, which will produce a higher level of open interest (Loop T6-b VI-20). Thus, in one case, a higher open interest led to a lower commitment (negative loop), in the other, a larger open interest produced an even larger level of open commitment (positive loop).

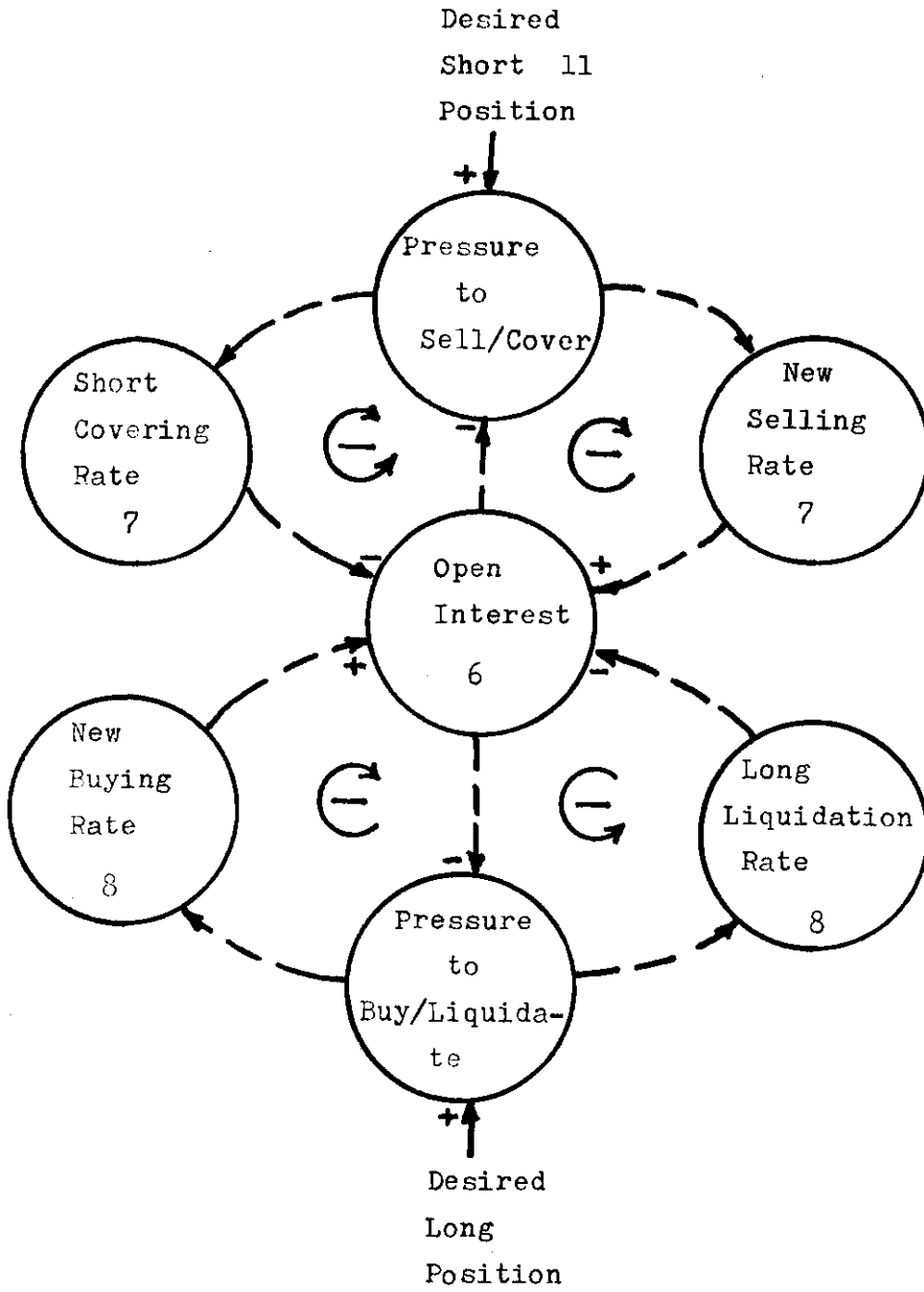


Figure VI-19. Loop Set T5: Open Interest.



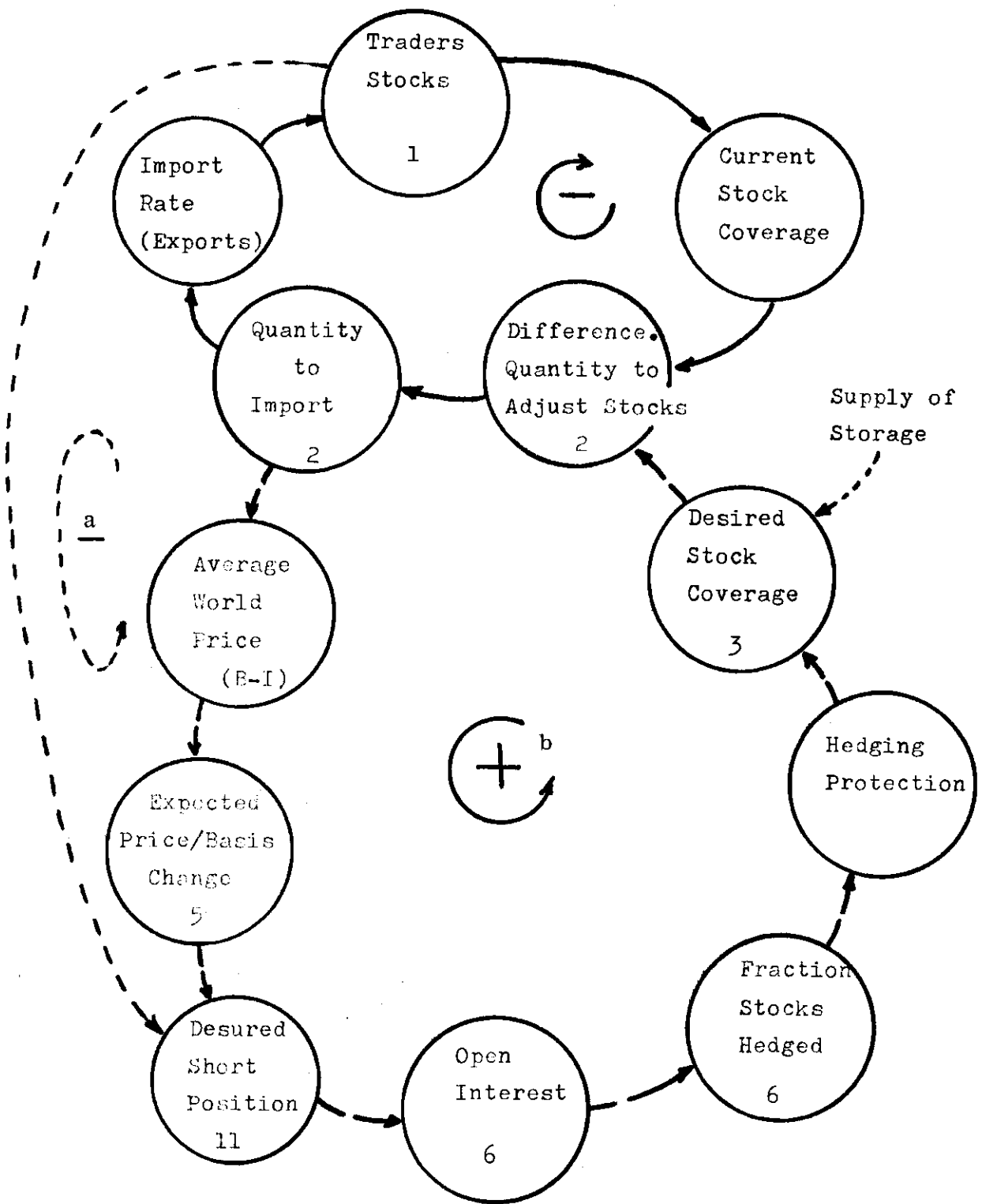


Figure VI-20. Loop Set T6: Hedging Protection.

The figure below shows several supply of storage curves (Figure VI-21) at different levels of short (hedged) positions. In particular, the figure shows

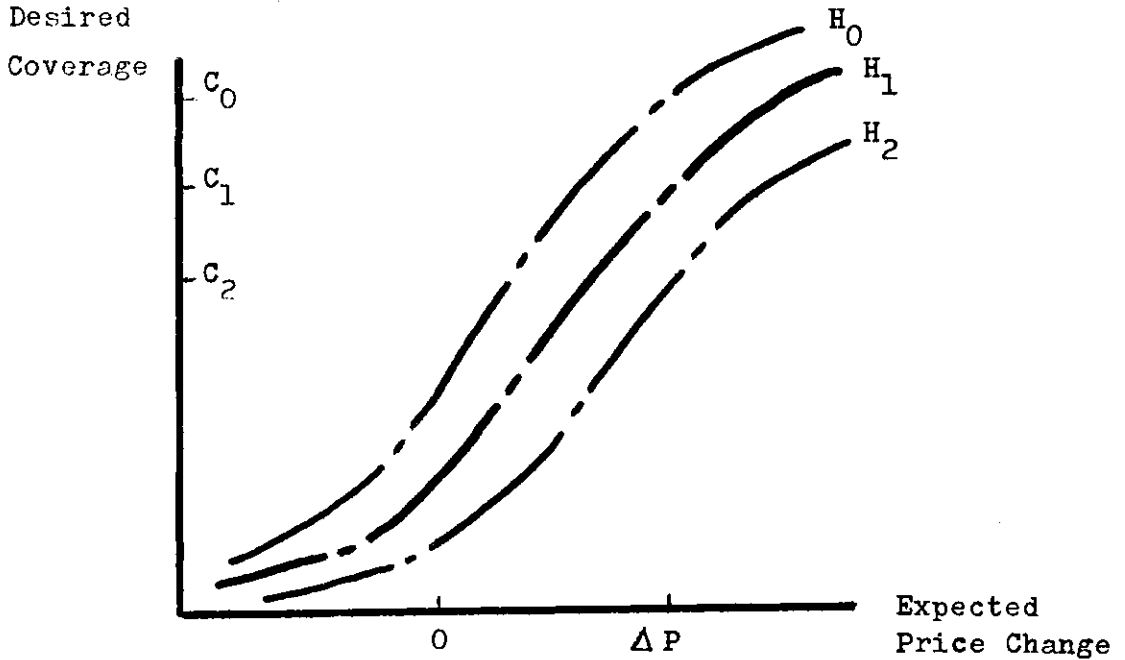


Figure VI-21. Supply of Storage at Different Levels of Hedging.

at a certain expected price change  $\Delta P$ , three different levels of desired coverage  $C_0$ ,  $C_1$ ,  $C_2$  at three different levels of established short position,  $H_0$ ,  $H_1$ ,  $H_2$  respectively. In the absence of a futures market, the trader would be unable to carry a portion of his stocks in futures, tending to maintain a larger coverage. Nevertheless, as the trader uses the future market to hedge an increasing portion of his stocks, he gradually raises his own protection against adverse price developments; this means that he will not require a coverage as high as before. Hence, as the fraction of stocks hedged rises from  $H_0$  to  $H_2$  in the figure, desired

coverage gradually declines from  $C_0$  to  $C_2$  years of supply.<sup>10</sup> The net effect of a reduced coverage, is to decrease the amount of physical stocks held. In fact, a trader who increases his short commitments in the futures market, is able to reduce his stocks by holding the reduced portion in the alternative form of future contracts.

e. Loop T7--Degree of Market Price and Export Controls (Quotas), Speculation, Open Interest and Volume of Hedging, Feedback Description.

Declining prices generate pressures on the supplier's side to establish market controls and export quotas. The lower the prices, the stronger the enforcement of these controls, which attract less and less speculation to the market. Hence, the desired speculative position (generally, a long position in the case of coffee) tends to decrease, which reduces both volume of trade and open interest and creates obstacles to use the market as an efficient hedging device. This in turn, reduces the degree of protection rendered by the market to the hedger, who now will have to carry the otherwise hedged stock of futures in physical inventory (higher coverage). The need to carry higher levels of physical inventories creates additional demand for green coffee. Thus, the desired quantity to be imported rises to meet supplies. In the face of poor availability of green coffee to satisfy the increasing demand, prices will not decay as fast as initially, and if availability further deteriorates, then prices will tend to recover and grow.

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<sup>10)</sup> The reader will find a more complete description of this process in Weymar [45, p. 39].

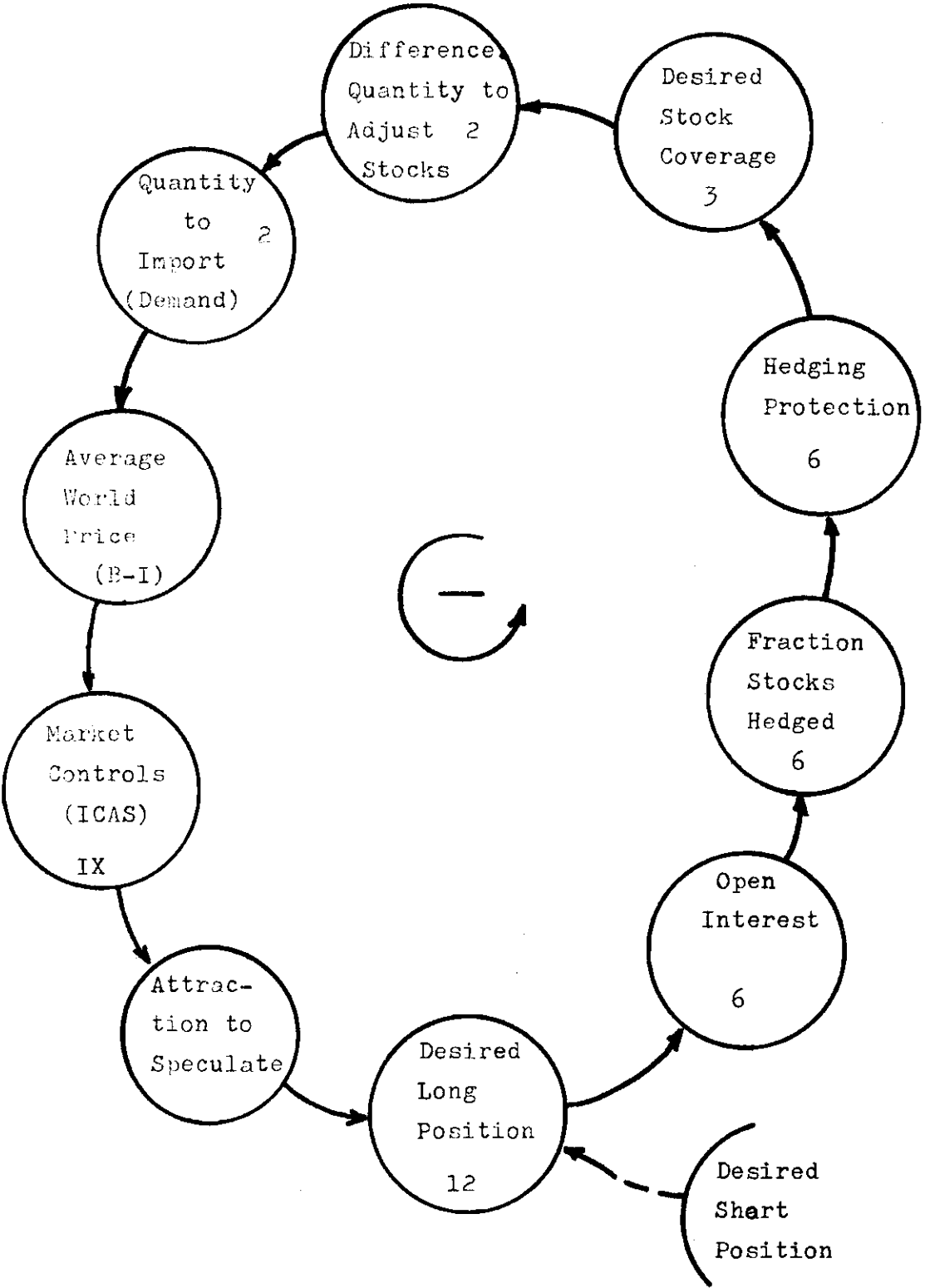


Figure VI-22. Loop T7: ICAs and Speculation.

Similarly, as prices rise, producers become less and less anxious to maintain and enforce market price and export quota controls. They will tend then, to relax or neglect the application of these control policies; hence, speculators will again appear in large numbers at the market place (Figure VI-22).

### C. Behavior of the Trade and Future Market Sector

#### 1. The Six-Year Coffee Cycle

The feedback structure of the Coffee trade-distribution system (Loops T1 and T2) interlocks with the feedback structure of the future coffee market (Loops T3 to T7) through feedback Loops T3, T6 and T7. The total trade and future market sector appears in Figure VI-23.

Figure VI-24 shows the behavior of the sector under a step increase in the amount of coffee sold per year. The system exhibits sustained oscillations of about 5.3 years of duration. Rising sales creates an upsurge in both spot and future prices (Loops T1 and T3). Coverage then tends to rise (Loop T2). As both coverage and stocks increase (Loop T1), traders intend to establish larger short positions, then, new selling rates, volume of trade, and open interest rise (Loop T6). At the same time, the rising prices motivate speculators to establish larger long positions, they will then buy new contracts to increase their commitment (Loop T4). Prices peak because current coverage has surpassed the target (desired) coverage, which tends to reduce traders demand and then, spot prices (Loop T1). As prices fall, a portion of the speculators tend to switch from a long to a short position, therefore the

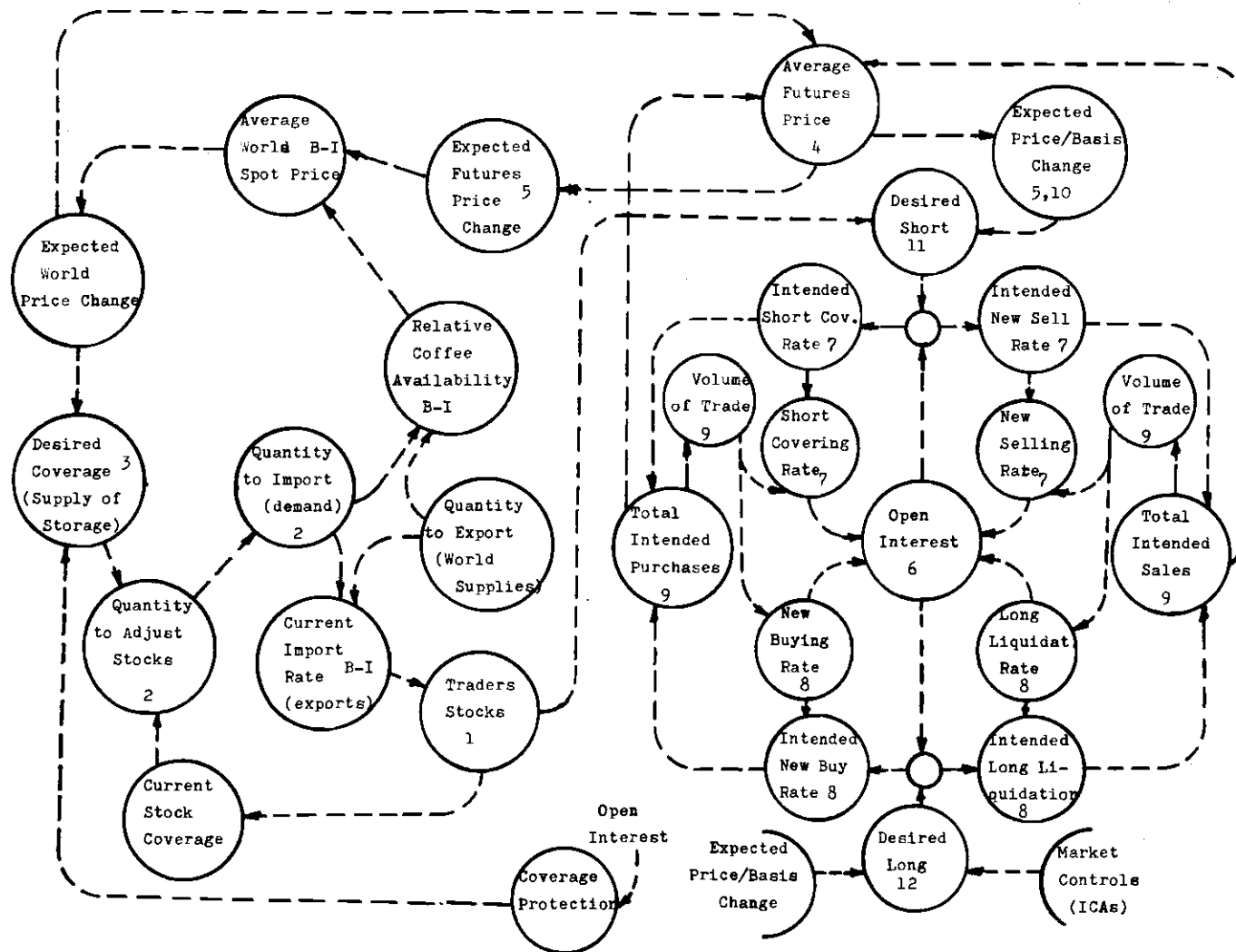


Figure VI-23. The Coffee Trade Sector.



futures price receives selling pressure; then, both futures and spot prices rapidly fall (Loop T3). Traders then reduce their desired coverage, and stocks also fall (Loop T1).

In the same figure stocks are seen to oscillate around an average of about 12.5 million bags. Had the performance been stable, stocks would have remained at this level after a certain time. Compare this value with the final value of stocks in Figure VI-7. In this figure, stocks reach steady state at about 14.5 million bags. Thus, the functioning of a futures market allows the trader to operate with a reduced average level of stocks, but unfortunately adds instability to his inventories.

Figure VI-7 showed the performance of the trade-distribution sector without a futures market. The behavior of this sector was stable, stability which was not affected when the parameters of the system were changed within reasonable extreme values. Therefore, the appearance of sustained (unstable) oscillations in Figure VI-24 can be entirely attributed to the policies and practices used by traders in the futures market, and fully described by Loops T3 to T7. In fact, one of the major reasons which affect stability in this market lies in the way traders establish their short- and long-target positions.

When prices rise, price-trend speculators tend to increase their long positions (See Figure VI-25); hedgers, on the other hand, in response to a narrowing basis will tend to reduce the fraction of stocks to hedge. Nevertheless, as prices rise they will buy stocks in advance to anticipate further price increases. Most likely the total desired short position will end up increasing



during this period (Desired Short Position = Stocks  $\times \Phi_H (\Delta B)$ ), but it could rise above or below the speculators desired long position. Open interest, however, will approach whatever of the two targets is the lowest. Assume open interest approaches a rising desired long position, i. e. Desired Long  $<$  Desired Short,

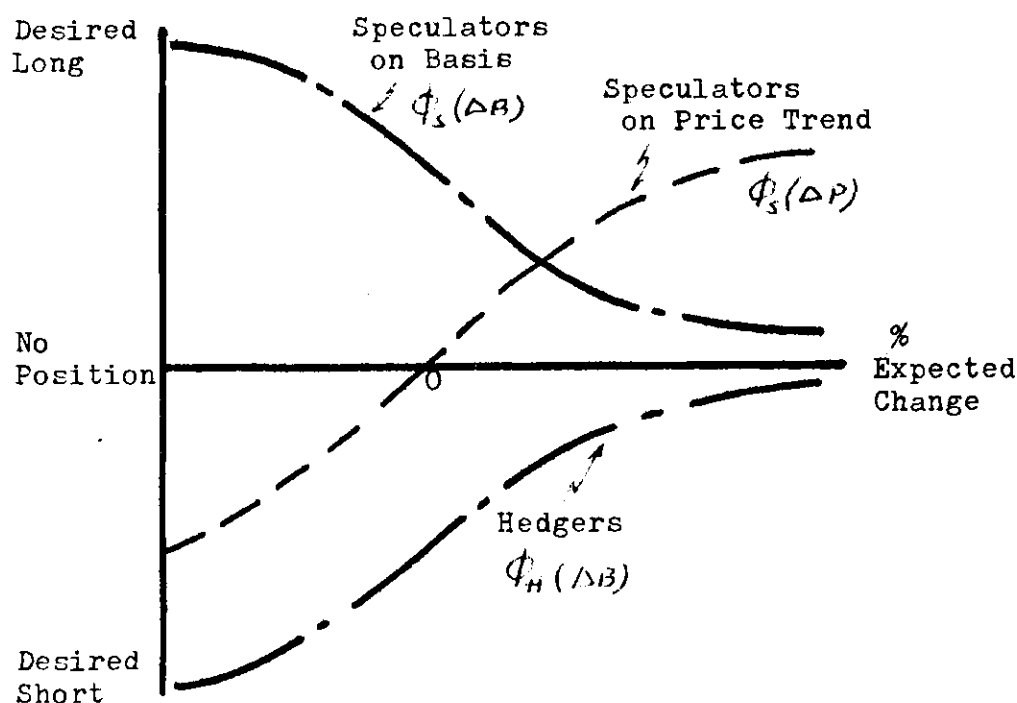


Figure VI-25. Hedgers and Speculators' Desired Position.

but both rising. Hence, speculators would gradually stop their trading as their current commitment equals their desired target. On the other hand, hedgers would be anxious to establish new short positions to achieve their new short target, a fact which creates selling pressure to depress prices. In turn, a negative change in prices (real or expected) affects speculators' needs; some

of them, the speculators on the spread, will want to increase their long commitments, others, the speculators on the price-trend will liquidate their older long position and switch to a new short position. Thus, on the aggregate, open interest will tend to exhibit a further increase, as shown by Figure VI-24.

The rise in open interest will not last long; rapid falling prices tend to reduce coverage and thus, physical stocks. Therefore, hedgers will now tend to liquidate a portion of their previous (short) commitment. Open interest then, will tend to fall. This completes the cycle.

Stable equilibrium in the future market requires, then, the fulfillment of at least three conditions. First, prices and expected prices should be at rest ( $\Delta P = 0$ ). Second, basis and expected basis should be also at rest ( $\Delta B = 0$ ), and third, the desired short position should be equal to the desired long position, and both equal to the current open interest. <sup>11)</sup>

$$(1) \Delta P = 0$$

$$(2) \Delta B = 0$$

$$(3) \text{Desired Short} = \text{Desired Long} = \text{Open Interest}$$

Conditions (1) and (2) insure that both, the desired long and short positions respectively do not change through time. In this case, the coffee market would tend to be an almost risk free market, and then, speculators or hedgers would not have strong motives to trade futures. Condition (3), on the other hand,

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<sup>11)</sup> Fey (54), (55) in two papers on feedback dynamics theory, discusses the behavioral effects of two different desired (target) values when controlling flow rates of change and accumulations. In general, target values based on conflicting interests produce unstable performance.

insures no additional buying or selling of contracts, and hence no price and basis change.

Figure VI-26 shows graphically, how unlikely it is for the coffee future market and its 'six' year cycle to attain stable equilibrium. The figure has been prepared from Figure VI-25. The broken line(s) represent the total desired long position by price-trend speculators and spread speculators as a function of price change.<sup>12)</sup> The solid line shows the desired short position by both hedgers and short speculators in the coffee market. Consider the intersection of curve (a) with the solid line. At an expected price change  $\Delta P_a$ , the two target positions would be equal, condition (3). Nevertheless, prices and basis are rising ( $\Delta P_a > 0$ ), therefore the equilibrium attained is not stable. On the other hand, stability would be obtained if say, curve (c) cuts the desired short position curve at point E, where  $\Delta P = 0$ , point where the stability conditions are met. In turn, several factors affect the position on the figure of the broken long speculative curve, one of which is the degree of export and quota controls. The likelihood that all of these factors combine to place 'exactly' the curve to cross point E is certainly remote.

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<sup>12)</sup> Spread speculators and hedgers take positions depending on expected basis change, not expected price change. We have shown, however that in the case of coffee, rising prices ( $\Delta P > 0$ ) leads to a narrowing basis ( $\Delta B > 0$ ) and vice versa. Hence Figure VI-26 is at best a rough approximation. It is presented here to clear the discussion about price stability.

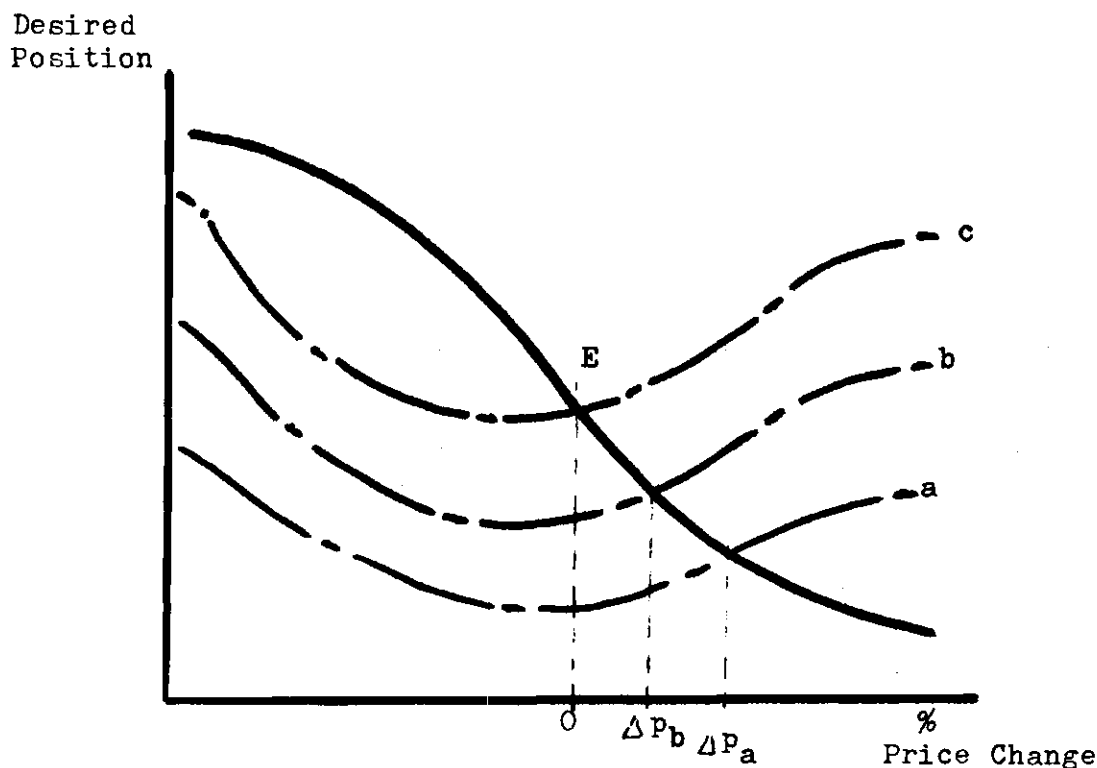


Figure VI-26. Equilibrium in the Futures Market.

#### D. Parameter Testing

Parameters are values which remain unchanged throughout the simulation run. In the Coffee Trade Model previously described, parameters were varied three-at-a-time, and up and down  $\pm 50\%$  from the normal value;<sup>13)</sup> a large change by all standards. All the simulations exhibited unstable (sustained) oscillations, with period varying from 4.19 to 9.65 years of duration, average about 5.3 years. As a sample, Figures VI-27 and VI-28 show the behavior of

<sup>13</sup> Appendix E shows the experiment design used to test parameters three-at-a-time. This experiment was designed by Dr. W. Low who allowed us to use it.

the model under a particular set of parameters. Table VI-1 shows the frequency distribution of the appearance of the 'six' year coffee cycle in all the 54 simulations performed.

Table VI-1. Simulated 'Six' Year Cycle

Midpoint of Wave Period (Years)	No. of Runs	Frequency of Appearance in All Simulations %
4.5	4	7.4%
5.5	37	68.0%
6.5	2	3.7%
7.5	4	7.4%
8.5	3	5.5%
9.5	4	7.4%
Total Runs	54	100 %

The above results imply that it is the operation of the feedback loops which compose the structure of the World Coffee Trade System, and not any particular choice of parameter values, which causes the appearance of a coffee cycle of about six years' duration.





## CHAPTER VII

### BEHAVIOR OF THE DYNAMIC WORLD

#### COFFEE MODEL (DWCM)

##### A. Coupling the Production and Trade Sectors

The Dynamic World Coffee Model (DWCM) postulated in this research contains two major subsystems--the production and trade sectors. The structure and behavior of each was described and explained in Chapters V and VI respectively. The main results obtained from these two chapters are summarized in Table VII-1.

This chapter displays the behavior produced by the World Coffee System when the two major sectors are coupled together. Figure VII-1 shows the main points at which the two subsystems interlock to complete DWCM. Recall the meaning of Quantity-to-Export, Quantity-to-Import, Export-Rate and the formation of World-Price.

$$\text{Quantity to Export} = \text{Exportable production} + \frac{\text{Producer-Stocks} - \text{Desired Level of Stocks}}{\text{PCT}} \quad (a)$$

This is the quantity offered by producers; exportable production is the difference between the current production rate and the domestic consumption. The second term of the above expression adjusts current producer stocks to the desired (target) level; PCT is the 'Producers Correction Time,' this is the period of time



Table VII-1. Behavior Produced by the Two Major Sectors  
of the Dynamic World Coffee Model

<u>1. Production Sector</u>	<u>Approximate Period of Cycle (years)</u>
a. Main Production Loops (P1 to P4)	30
b. Abandonment Loop (P5)	15
c. Effective Yields Loop (P6)	8
d. Obsolescence Loops (P7, P8)	Other harmonics of shorter period.
<u>2. Trade Sector</u>	
a. Trade and Distribution Sector. Loops (T1, T2) (Without future market)	4.8
b. Trade and Future Market Loops (T3 to T6)	5.5

required to drive stocks near target value.<sup>1)</sup> PCT is a parameter established by the producers' management. In the basic simulation run, it has been assumed to be equal to one year.

The 'Quantity to Import' or traders' demand is given by the following expression:

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<sup>1)</sup> All simulations performed on the Coffee Trade sector in Chapter VI, assumed a constant 'Quantity to Export.' The value was set large enough to satisfy traders' demand.

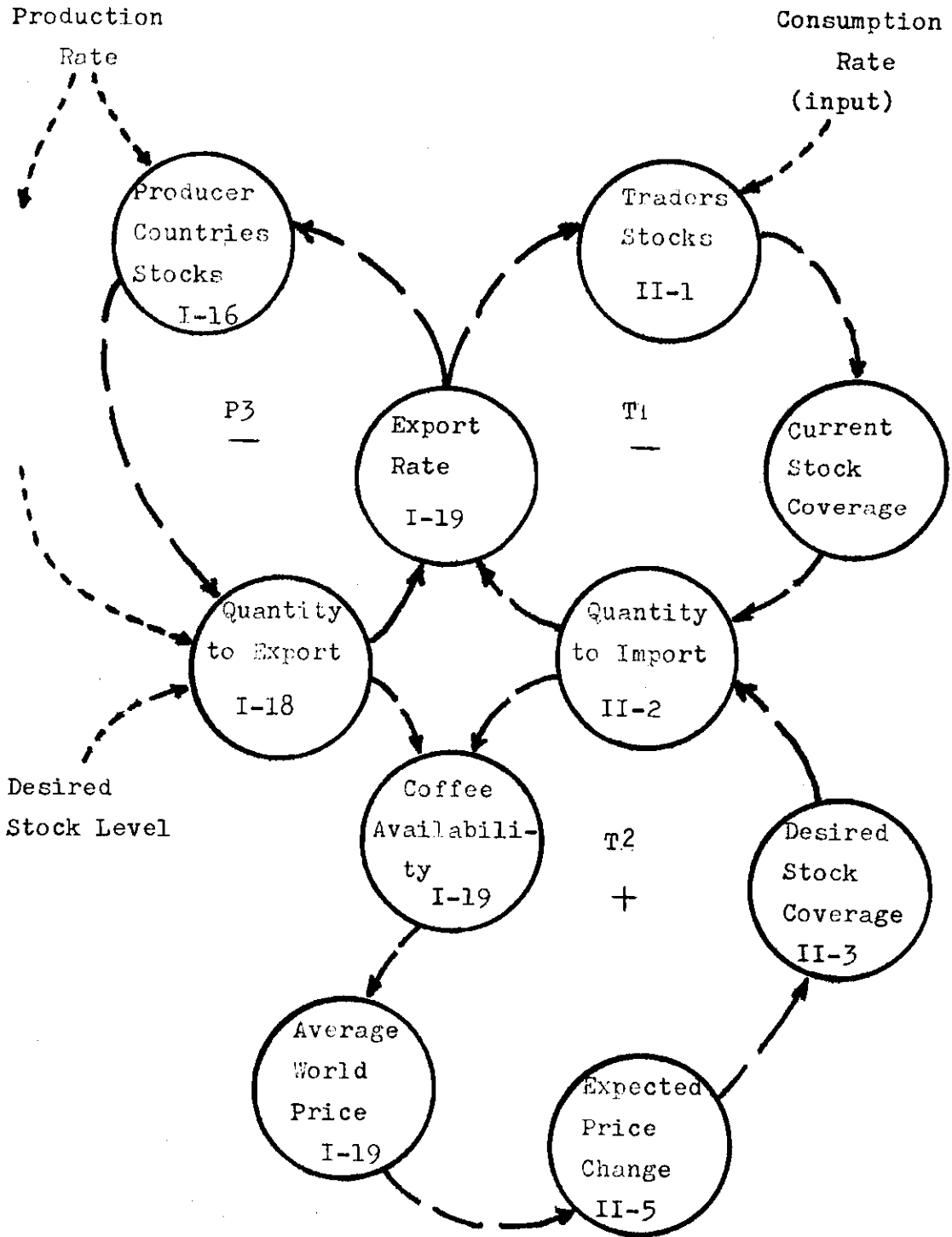


Figure VII-1. Coupling the Production and Trade Sectors.

$$\text{Quantity to Import} = \text{Average Consumption} + \frac{\text{Desired Traders Stock} - \text{Trader Stocks}}{\text{TCT}} \quad (b)$$

where the 'Desired Traders Stocks' is given by the target coverage in years-of-supply. TCT is the 'Traders Correction Time,' the period of time required for the traders' stocks to approach their desired (target) value. In the basic simulation runs, TCT has been taken as 0.5 years.<sup>2)</sup>

Chapter V described the bargaining process normally used by producers and traders to establish both the actual volume of exports and its price (loops P2 and P4). A result of this bargaining process implies that the current amount to export, i.e. the export rate, can be formulated by the average between the original quantity offered to be sold, i.e. the 'Quantity-to-Export,' and the original traders' demand, i.e. the 'Quantity-to-Import.' Further, the larger the discrepancy between the two quantities, the lower or higher the quoted price to carry out the commercial transaction.

$$\text{Export Rate} = \frac{1}{2} \{ \text{Quantity to Export} + \text{Quantity to Import} \} \quad (c)$$

$$\text{Price} = \Phi(\text{Quantity to Export} - \text{Quantity to Import}) \quad (d)$$

The above equations link the Production with the Trade Sectors.<sup>3)</sup>

<sup>2)</sup> To develop the simulation runs on the Production Sector (Chapter V), the 'Quantity to Import' was forced to follow exponential growth.

<sup>3)</sup> Loop T3 in Chapter VI shows other links. This loop relates future-price to spot prices and vice versa. Furthermore, the existence of a system of export quotas (ICAS) provide still other links in the sense that it affects speculative transactions in the future market.

### B. Behavior of the Basic Simulation Run (DWCM)

Figure VII-2 shows the behavior of the DWCM when the two sectors are coupled together. In this and the subsequent simulation runs, the input to the model is the pattern of annual consumption of coffee ('U' in the plots); it has been assumed to grow exponentially beginning with 8 million bags a year by 1885 and reaching 58 million bags a year by 1970. This pattern roughly approximates actual consumption rates.

In the figure, the behavior of world prices exhibits a long cycle of about 32 years, and the shape of the wave suggests the presence of harmonic cycles of 16 and 8 years; this feature was previously described in Chapter V. From the figure however, it is difficult visually to observe a recurrent six year cycle generated by the Coffee Trade Sector. Nevertheless, a comparison of Figure VII-2 with the behavior exhibited by the production sector in Figure V-19 (repeated here for convenience) presents clear evidence that one effect of the trade sector is to create wider oscillations combined with several movements not previously found in the behavior of the production sector. In particular, note in Figure VII-2 a five year cycle from 1945 to 1950, and a similar one from 1974 to 1979.

The behavioral pattern of annual production rates grows above and below the pattern of exports (letter E in the plot), and exhibits peaks at 1907, 1934, and 1964, a span of 27 and 30 years respectively. Similarly, the production pattern presents other peaks at 1920, 1951 and 1981, a span of 31 years in each case. Furthermore, the elapsed period of time between each peak and the next





one is 13, 14, 17 and 17 years respectively. Therefore, the production pattern reflects a major cycle of about 32 years, together with a harmonic cycle of about 15 years duration.

The behavior of the producer stocks displays a major cycle of about 30 years; a cycle whose amplitude widens over the simulated years. Intertwined with this major movement, there appears a minor cycle of about 15 years. The fact that stocks exhibit unstable oscillations--widening amplitude--together with the fact that prices peak when stocks are almost totally depleted, is a characteristic of the coffee industry, as initially described in Chapter II and graphically depicted by Figure II-1.

A reason to explain the rapid depletion of stocks as prices rise lies in the coupling of the production with the trade sector. When both production rates and stocks fall, a reduced quantity is supplied at the market place, i.e., the Quantity-to-Export in expression (a); consequently, as supplies become scarce prices then rise like during the mid fifties in Figures VII-2. A well established price trend forces traders to purchase in advance to avoid higher prices in the future. Thus, they will increase their desired coverage, their stock and also their demand to suppliers (Loop T2, Figure VI -1). Hence, the Quantity-to-Import tends to rise (see expression (b)). Therefore, over the period, the quantity supplied at the market place falls while the quantity demanded rises. This situation gradually causes worldwide coffee scarcity with rising prices (expression (d)).

On the other hand, the fact that demand rapidly rises while supplies fall, may establish a rising or falling export rate (expression (c)) depending upon which

of the two sides of the market is stronger. In any case however, the already falling stocks will tend to be depleted much faster, because production rates stay below the export rate during the period (See Figure VII-2, from 1952 to 1960).<sup>4)</sup>

Figure VII-2 exhibits certain phase relations among prices, production rates and stocks. Generally, the major peaks in the producer stocks reach a maximum about ten years later than prices and about five years later than production. Similar phase relationships were also found in the actual patterns of behavior of these variables in the coffee industry. (See Chapter II, Section A, and Figures II-1 and II-2.)

### C. Behavior of Small and Large Producers

This section tests the effect on behavior of the stock policy followed by the small and the large producers (Loop P9, in Chapter V). Expression (a) in this chapter, describes the Quantity-to-Export (world supplies) as the result to add the exportable annual production with a second term whose effect was to adjust current stocks to their desired (target) value. Loop P9, on the other hand, postulated that the desired level of stocks in years of supply was a function of the foreign cash reserves of the producer nation(s). In turn, the shape of the function

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<sup>4)</sup> Further explanation of the cyclic behavior in Figure VII-2 and the ones to follow is omitted in the chapter. See the portions of Chapters V and VI that describe the production cycle (32 years) and the trade cycle (6 years).



was the result of the power of the nation(s) to manipulate world prices (Figure V

The rationale presented there was the following: when prices fall and the foreign cash reserve of a small producer deteriorates, the small producer unable to manipulate price formation tends to supply a larger amount of coffee to the marketplace to augment its flow of foreign earnings. To accomplish this objective, the producer will attempt to store a reduced (target) stock, thereby increasing the Quantity-to-Export (expression (a)). The effect of a fall in prices would be to augment the world coffee surplus; prices then would fall faster than initially (Positive Loop P9).

The effect of this type of relation on behavior appears in Figure VII-3. Note that the plots exhibit stronger unstability than in previous runs; this is a natural consequence of the functioning of the positive loop P9; a rapid price fall tends to produce too low planting rates, a fact which creates abnormally low capacity several years later. At that time then, prices will grow rapidly.

Figure VII-4 displays the behavior of the large producer. In this case, the producer nation powerful enough to retain stocks and alter price tends to enlarge its desired level of inventories when its foreign cash position deteriorates; thereby, the Quantity-to-Export declines (expression (a)). Loop P9 then, becomes a negative loop: as prices fall and the producers' foreign cash position decays, world supplies become tight. Hence, prices will tend to rise. The effect of the negative loop P9 is to smooth out the oscillations exhibited in the previous figure.

The two plots however, show again the same basic behavioral characteristics depicted by all previous simulation runs: this is, cycles, period, wave



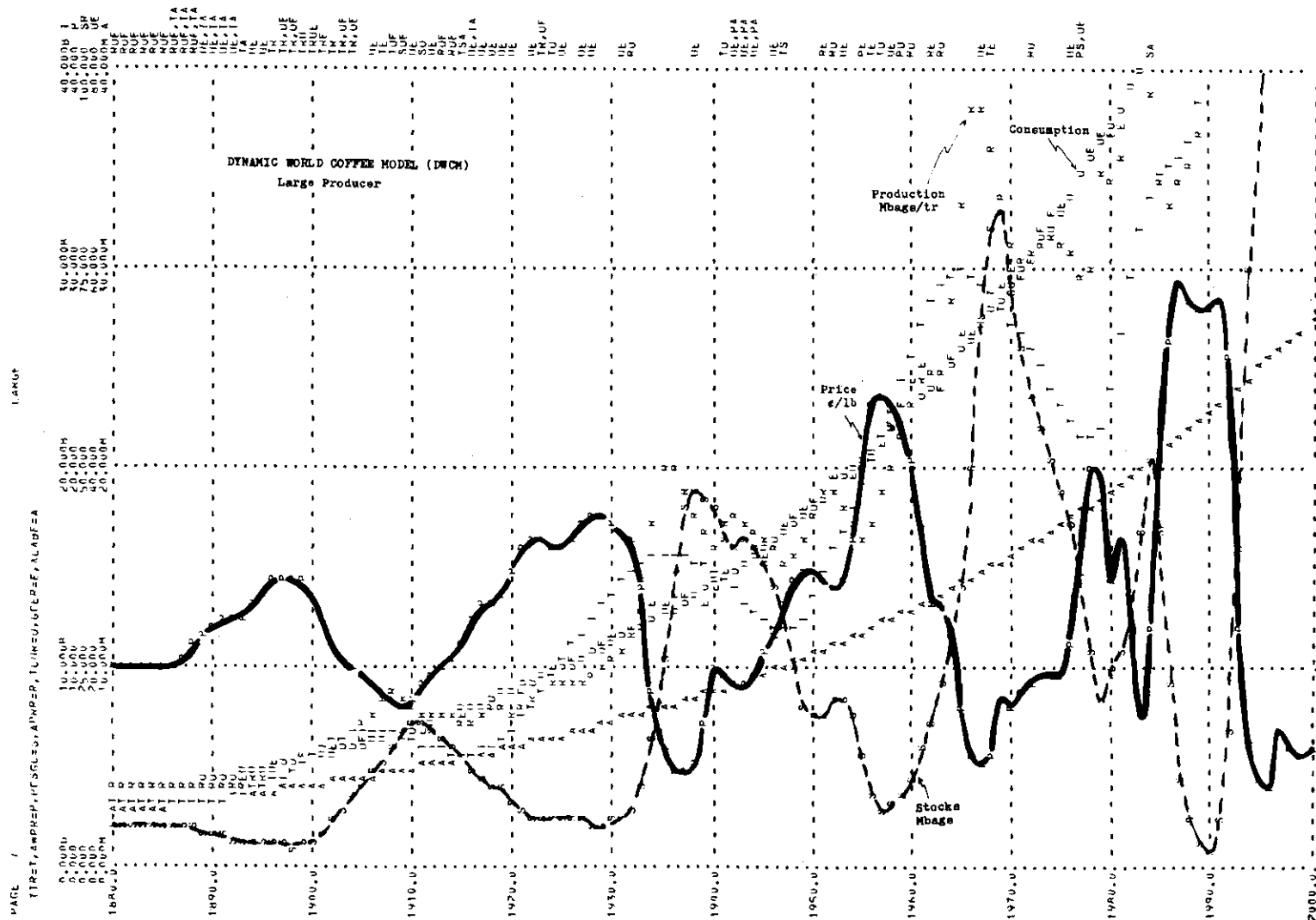


Figure VII-4. Behavior of Large Producers.

shape and phase among the variables remain almost the same. Although both figures display unstable performance, the behavior of the small producers tends to add more instability than the behavior of the large producers. This is the main conclusion of this section.

#### D. Parameter Testing and the Behavior of the DWCM

Parameters in a model are quantities that do not change throughout time. The Average-Number-of-Hectares-per-Tree (HAPTR), the Percentile Yearly Growth-in-Agricultural-Labor-Force (PYGAL), the Producers-and-Traders Correction-Times (PCT and TCT) are examples of parameters in the DWCM. Throughout a simulation run, each one of these quantities remains constant.

Over a long period of time, however, parameters in a dynamical system may change. The DWCM assumes that possible variations in the model parameters over the simulated period do not have a relevant effect on the behavior of the system. To see how valid is this hypothesis, the DWCM was simulated with different parameter values and the parameters were chosen both one-at-a-time and then three-at-a-time.<sup>5)</sup> Within a variation of  $\pm 40\%$  to  $\pm 50\%$  from the normal parameter value, the behavior produced by the DWCM generally exhibited similar cyclic and phase characteristics. The fact that non-linear feedback loops tend to compensate the effect of a variation in parameters is a well known characteristic of feedback dynamic models previously developed (Forrester [57, p. 172]).

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<sup>5)</sup> Chapter VII and Appendix E briefly describe the experimental design used here.

TIR=T,AMPNEP,PTSCES,APNPR,TUIN=U,UCER=F,ALAUFE=A

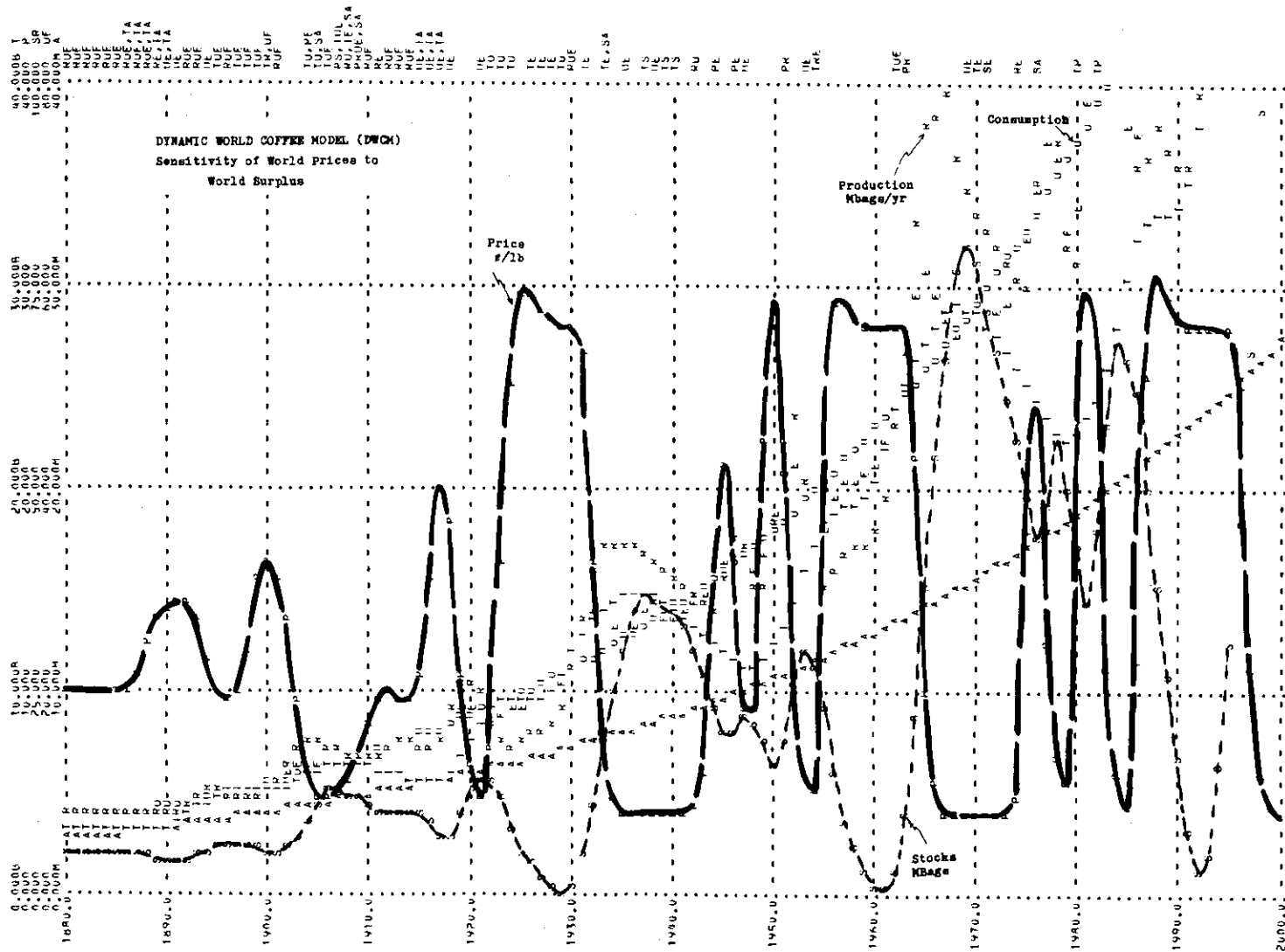


Figure VII-5. Sensitivity of World Prices to World Supplies.



Figure VII-5 shows the behavior of the DWCM when the Traders-Correction-Time (TCT in expression (b)) is reduced from 0.5 to 0.24 years.<sup>6)</sup> The behavior is again basically the same as the one exhibited by the basic run in Figure VII-2. Here however a five year cycle originated in the Coffee Trade Sector displays larger unstability. Traders who want to adjust their stocks to their desired target too fast (TCT = 0.25 years) normally end up with wild inventory oscillations.

Figure VII-6 shows the behavior of the DWCM when prices are made to respond more rapidly to unbalances between supply and demand. In the basic run, an excess or shortage of green coffee less than 2 million bags did not promote too much price change (Availability-Significant-Difference AVSD = 2, in equation of Appendix B-I). In the current run, the market is made more sensitive to excess or shortage; AVSD = 1 million bags. The plot exhibits higher unstability than before, as reflected by a wider amplitude in the six year Trade-Cycle and the rapid fall and rise in both prices and stocks. Nevertheless, despite the change in parameter value, the behavior exhibited by the DWCM displays the similar composition of cyclic movements previously described. Furthermore, stocks still exhibit unstable oscillations and the phase relations among production, stocks and prices remain unchanged throughout the experimentation.

Figure VII-7 displays the behavior of the DWCM when the annual growth in agricultural labor force (PYGAL) reduced from 3% to about 2.5% per year. Note the

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<sup>6)</sup> Two other parameters were changed in this run. WPSD and WFPSD both from an original value of 7.5 to one of 5. A reduction in these two parameters, together with the reduction of TCT, increases the sensitivity of traders to adjust coverage, and the effect of the future market upon spot prices.

reduction of the amplitude of the wave. In fact, when the DWCM is simulated with a lower amount of available labor, it becomes more costly and difficult to the farmer to expand acreage and plant new trees (loop P1). Therefore, if prices rise over a period, the amount of accumulated excess capacity tends to be lower; hence, production rates and stocks will not grow too fast and prices will not tend to fall to the lowest values. The reader should recognize here the effect of the main feedback loop P1 on behavior. A reduction in labor growth has the effect of diminishing the dominant role of this loop on the DWCM. Then a way to reduce unstability in the world coffee model is to control the pool of available labor to grow coffee.

### E. Summary

DWCM displays a long cycle of about 30 years combined with a harmonic cycle of 15 years of duration. Intertwined with this long movement, there appears a six year 'trade' cycle. Producer stocks display unstable oscillation; stocks peak about ten years later than prices, and around five later than production. These characteristics are typical of the World Coffee Economy, as described in Chapter II.

Parameter changes do not tend to affect this type of behavior. Therefore, the behavior rendered by DWCM is more the result of its feedback structure than the result of a particular choice of parameters.

The behavior of the small producers tends to add instability to the World Coffee System. More importantly, a way to reduce the unstable performance of the world coffee economy is to control the flow of available labor to grow coffee.



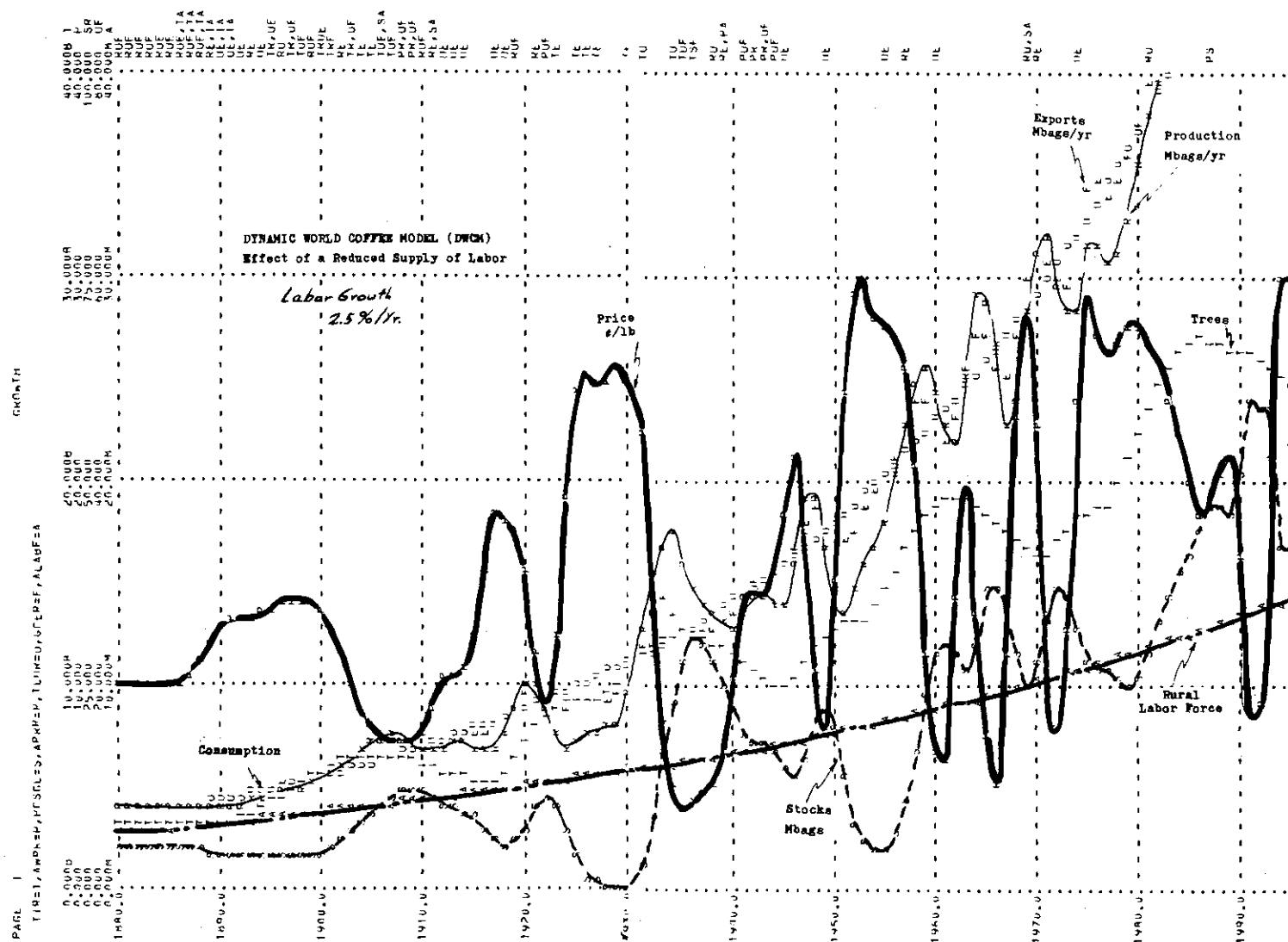


Figure VII-7. Reduced Growth in Labor Force.

## CHAPTER VIII

### SUMMARY OF VALIDATION PROCEDURE

Validation is the process of assessing how close a dynamic model resembles the system under study. This chapter presents a summary of conclusions in previous chapters which support the Dynamic World Coffee Model postulated in this research. The chapter is divided into four sections. The first section compiles evidence from Chapter IV to attest the existence of postulated coffee cycles. The second briefly describes the process of structural validation, loop assessment and model verification. The third compares the behavior generated by DWCM with the actual patterns of behavior of the world coffee economy.<sup>1)</sup> Finally, the fourth section shows that the behavior of DWCM is more the result of the feedback structures which compose the model than the result of a particular choice of parameters.

#### A. The Coffee Cycles

The coffee cycles postulated in this thesis appear in Table VIII-1. This research claims that there is 80% chance that the cycles displayed by the world coffee price and production series are not the result of random events. This claim is further supported by the following additional findings in Chapter IV:

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1)  
Wright [58, p. 40-43]

Table VIII-1. Cyclic Movements in the World Coffee Economy

Cycle Name (years)	Harmonic (years)	Probability that Cycle is not * Spurious	Elements of DWCM that Generate Cycles of Similar Frequency
32	16 8	80%	Main production loops P1 to P4 Abandonment loop P5 Effective Yields loop P-8a
6	1.5	80%	Trade Distribution and Future Market Sector
3 2		90% } }	Not included in DWCM

\* Variance of the power estimate as a function of frequency can be roughly removed by drawing a smooth curve through the power estimate. If this curve makes an excursion beyond the  $\chi\%$  confidence band, then there is approximately  $\chi\%$  confidence that the excursion did not occur by chance (following [52]).

1. Both the spectral plots of the price series (1825 to 1972) and the Brazilian production (1856 to 1972) and the Brazilian production (1856 to 1973) display a similar frequency composition (Figure IV-12).
2. The presence of harmonic cycles of shorter duration suggests the existence of the major fundamental movements.
3. More importantly, when the postulated cycles and harmonics were combined into a mathematical expression to rebuild the price series since 1880, the estimated series exhibited remarkable similarities with the real price series with respect to period, shape, number of peaks and amplitude (Figure IV-8).

### B. Structural Validation of DWCM

Structural validation is the process of assessing how well the postulated model describes the mechanisms, procedures and policies actually followed by farmers, traders and governments in the coffee economy. Structural validation contains two salient steps: (1) loop assessment, (2) model verification.

Loop assessment is the appraisal of the capability of each feedback loop to describe the organization, policies and practices depicted by the system, and to establish which feedback loops are relevant to behavior and which others can be omitted. The loops postulated in this research are plausible. To assess their presence in the system the author undertook an extensive research on coffee history,<sup>2)</sup> read numerous economic publications on coffee, held discussions with several Brazilian and Colombian farmers, and discussed DWCM with a well-known processor of coffee in the United States.

Both Chapter V on the coffee production sector and Chapter VI on the coffee trade sector give references supporting the postulated relations. The chapters present charts and factual evidence to attest the correctness of certain relationships. The two appendices BI and BII give additional literature references in support of the hypotheses postulated in the microstructure of the loops. In several situations, however, the author did not find bibliographical references to support postulated relations. The appendices describe these relations as 'assumptions' which require further investigation. A list of the assumptions appears in Chapter X, Section C. Recommendations for Further Research.

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<sup>2)</sup>On coffee history: [11], [20], [22], [24], [25], [33].

Model verification is the process of insuring that the relations depicted by each loop are properly translated into the mathematical model. This is one of the purposes of describing verbally and then in mathematical form each one of the equations contained in DWCM. These descriptions appear in Appendix BI and BII.

Model verification also involves the checking of typographical errors in the model equations. A computer printout of all the model equations is included at the end of each of these two appendices. Equations in the printout appear in the same order as they appear in Appendix B.

### C. Behavioral Validation of DWCM

If a model is a good representation of the actual system, it should be able to replicate the behavioral characteristics of the system. Behavioral characteristics refer here to wave shape, period, phase relations among variables, amplitude, and stability.

Chapter V of this research has shown that the coffee production sector of DWCM contains feedback structures whose behavior displays a major 32-year cycle and two of its harmonics. These results appear in Table VIII-1. In particular the chapter showed that the main production loops P1 to P4 generate an unstable coffee cycle of about 30 years in duration; that the abandonment loop P5 causes a lagged harmonic of about 15 years, and that the effective yield loop P-8-a causes a harmonic of about 8 years. In turn, Chapter VI showed that the coffee trade sector generates a cycle of about 6 years in duration.

Furthermore, the behavior displayed by DWCM in Chapter VII exhibits characteristics similar to the actual behavior of the world coffee economy since the year 1885. Prices, production and stocks exhibit similar waves in the simulated runs to those generated by the actual system. Phase relations among these variables closely resemble the actual phase relations; stocks peak about 10 years later than prices and roughly 2 or 3 years later than production (Figures VII-2, II-1 and II-2).

The behavior of the producers' stocks in DWCM presents the type of unstability exhibited by producer inventories in the world coffee economy--a long cycle of about 32 years in duration with widening amplitude. In fact, stocks fall to near depletion levels when prices peak; and each oscillation is wider than the previous one (Figures VII-2 and II-1).

Table VIII-2 summarizes the above results. The third column of the table presents the approximate value of prices, production and stocks in four sample years. Although the purpose of building DWCM is to explain coffee behavior, not to predict values on the variables, these values allow the reader to appreciate the range of operation of the depicted variables. Certainly DWCM is able to function within a range of values close enough to resemble the behavior of the world coffee economy.

Figure VIII-1 presents the spectral plot(s) of the world coffee price series (these spectra appeared in Figure IV-5). The thick broken line shows a typical spectral plot of the simulated price series. Note almost concurrent peaks when

Table VIII-2. Behavioral Comparison Between the Simulated Behavior (DWCM)  
and Actual Behavior of the World Coffee Economy

Variable	Major Cycle (years)		Approximate* Value During Year Sample			Approximate Phase Among Variables with respect to prices (years)	
	DWCM	Actual	Years	DWCM	Actual	DWCM	Actual
World Prices (real ¢/lb)	31	32	1925	25	25		
			1935	4	8		
			1955	30	27	-	-
			1965	4	8		
-----							
Production (Million bags per year)	30	32	1925	18	25		
			1935	40	30		
			1955	35	45	8 ~	5 to 10 (but not clear in Figures II-1, II-2)
			1965	90	70		
-----							
Producer Stocks (Million bags)	30	32	1925	6	10		
			1935	40	25	10 ~	10~
			1955	10	10		
			1965	70	70		

\* Approximate values taken from actual data, Figures II-1 and II-2, and from the simulated behavior in Figure VII-2. Presented here for range comparisons, not for point-to-point comparisons.

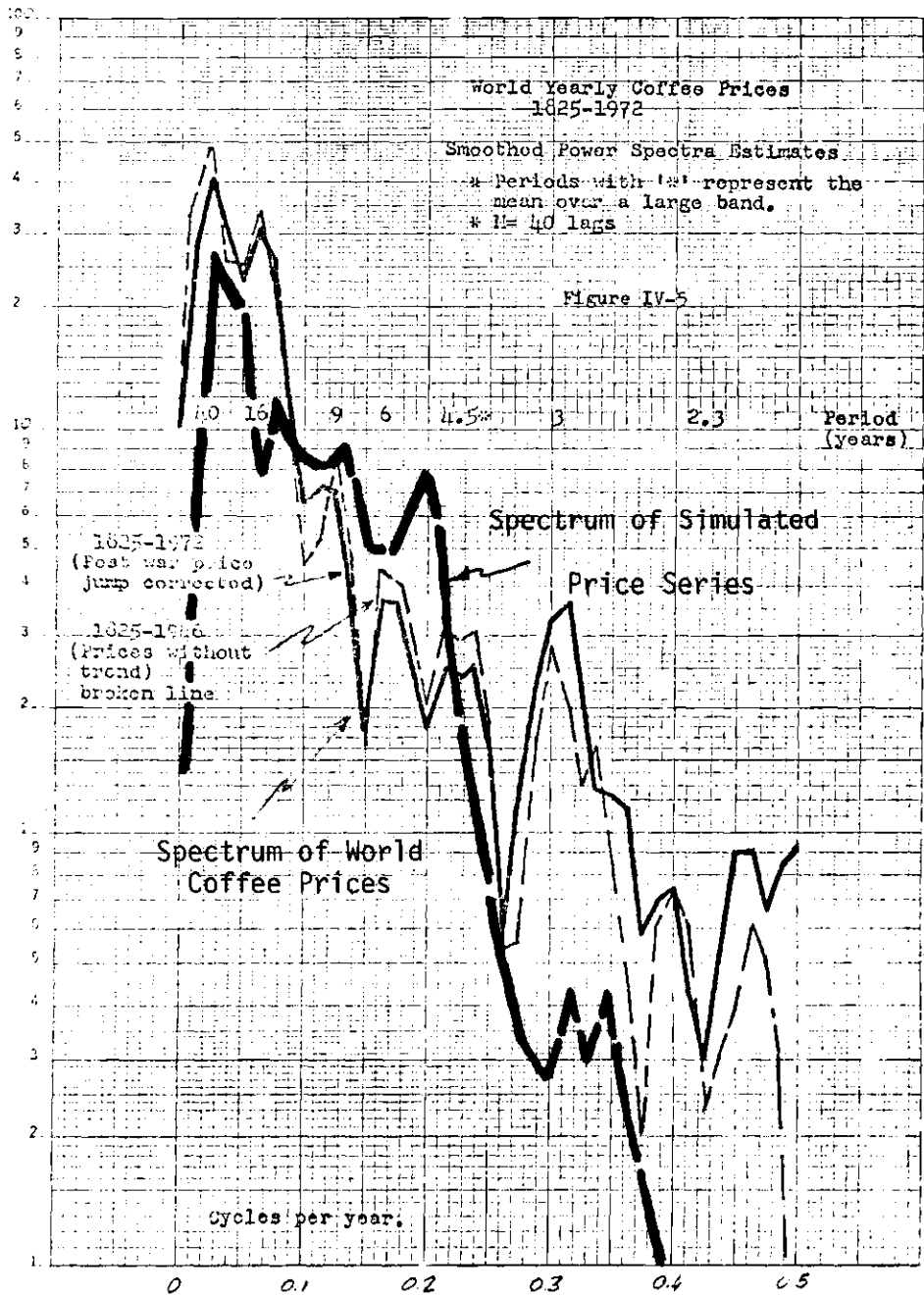


Figure VIII-1. Spectra Plots of Actual and Simulated Data.



one compares the two spectral plots at 40, 16, 9, and 6 years.<sup>3)</sup> Therefore, the diagram shows that the simulated price series contains similar cyclic composition to the actual coffee price time series.

#### D. Parameter Testing

The characteristics of behavior of the World Coffee Economy are more the result of the operation of the feedback structures embodied within DWCM than a particular choice of parameters. To assess the validity of this hypothesis, extensive parameter testing was conducted on DWCM. Parameters in the model were chosen three-at-a-time and were varied up and down  $\pm 50\%$  from the normal value, as shown by the experimental design in Appendix E. A change of  $\pm 50\%$  in parameter values is abnormally large by any standard. The DWCM exhibited very similar behavior under this experimentation. From a total of 108 simulation runs, 65 produced a long cycle whose period was within 25 and 35 years. Table VIII-3 shows the frequency distribution of the appearance of the 32 year cycle.

The results imply a probability of about 80% that DWCM exhibits a cycle of more than 25 years when parameters are varied up and down 50% of their normal value. Therefore, the presence of this cyclic movement is more the effect of the feedback loops in the model than a particular choice of parameter values.

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<sup>3)</sup> Chapter IV established the peak at 40 years as the 32 year cycle; also the peak at 9 was redefined as a peak at 8 years.

Table VIII-3. Frequency Distribution of the Appearance of the 32 Year Coffee Cycle when Model Parameters were Varied  $\pm 50\%$  on a Three-at-a-Time Experiment

<u>Range of Wave Period (years)</u>	<u>No. of Runs</u>	<u>Frequency %</u>
35, 40	19	17.59
30, 34.9	35	32.41
25, 29.9	30	27.78
20, 24.9	11	10.18
15, 19.9	3	2.78
10, 14.9	9	8.33
5, 9.9	1	0.93
Total Runs	108	100%

## CHAPTER IX

### INTERNATIONAL COFFEE POLICY AND THE STABILIZATION OF PRICES

This chapter contains two major sections. The first one, tests the effects on behavior of two 'stabilization' policies frequently advocated by scholars, administrators, and policy makers in the coffee business. The second section of the chapter constructs a new policy and tests its effects on the stability of coffee prices.

#### A. Traditionally Recommended Policies

##### 1. The Effect of an Export Quota Policy (ICAS). (Loop P10, in Chapter V)

On December 3, 1975 the NFTC Digest<sup>1)</sup> published the following description of a newly signed coffee agreement:

Re: Coffee: Coffee negotiators reach agreement in London on a new 6-year coffee accord to take effect next Oct. 1; final polishing remains, but last minute compromises by the U.S. and Brazil brought a breakthrough to the new treaty which will regulate world trade in coffee; essentially, the U.S gave way on its demand for applying penalties to nations which do not ship the full amount of their market-share quotas; Brazil, together with other concessions, accepted a slightly smaller slice of the world market than its traditional 33%. The negotiators sought to make the new agreement much more flexible than is typical of commodity agreements; supply-reducing quotas won't even be imposed unless prices drop to one of two trigger points: average '75 prices or 15% below the average for the year before the one under consideration; in another innovation, the new pact provides that quotas can be suspended, once in effect, if prices rise 15% above their previous-year average. J,WSJ/28

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<sup>1)</sup> Noticias, National Foreign Trade Council, Inc., New York.

The above paragraph clearly relates the establishment of export quotas to (average) prices. In fact, each one of the previously implemented ICAs have characterized by a similar type of relationship: the lower the level of prices the lower the quota and the reduced the quantity supplied at the market place; and conversely, the higher the level of prices, the higher the quota and the larger the actual quantity of coffee released to the market.<sup>2)</sup>

Figure IX-1 displays the effect of prices on export quotas. The horizontal

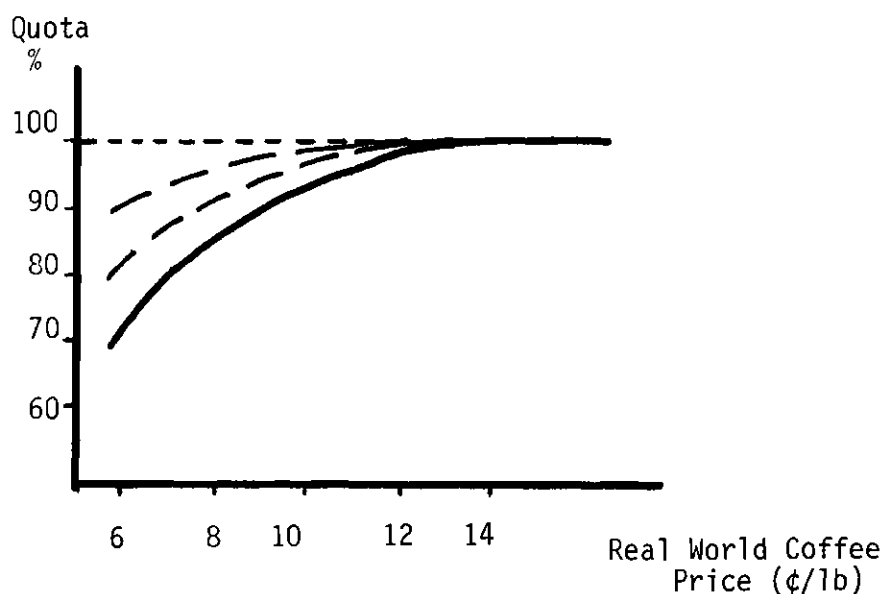


Figure IX-1. Effect of Prices on Export Quotas.

axis shows the level of average world coffee prices (AWPR), in real U.S. ¢/lb. The vertical axis shows the percent of exportable supplies which each year is retained when prices fall below the average value of 12¢/lb. The policy depicted

<sup>2)</sup> The reader may find a complete description of the 1962 and 1967 ICAs in Geer [ 13 ], Rowe [24, 25] and [ 15 ].

by the diagram indicates that a lower level of prices induces a lower fraction of export quotas; and conversely, as prices rise above their average, quotas tend to be relaxed. Figure IX-1 presents three different quota-price relationships. Each one of these reflects the same type of policy, although the actual fraction of retained exports is different in each case. In particular, the solid line depicts a case in which larger percentages of the exportable supplies are retained from the market place.

Export quotas not only depend on the average price level; they are also affected by the rate of price change. This means that producers and consumers tend to respond one way when prices are high (low) and falling; but they will respond different when prices are high (low) and rising.

Initially, when prices decay, the system of export quotas tends to be carefully enforced by suppliers. Nevertheless, if prices fall too fast, there always exists the temptation on the part of the smaller producers to default on their quotas and 'dump' additional supplies to the market place. Hence, the effective quota to the market tends to be higher than it should be.

When prices rise, producers lose interest in the enforcement of the quotas; therefore, pressures to establish a worldwide agreement shifts from the supplier side to the consumer side. Consumers then will be willing to offer a variety of trade concessions to suppliers on the condition that they relax their quota fraction. Hence a too rapid price increase also tends to induce default on quotas; the effective quotas to the market will again be higher than agreed.

The above ideas are captured by Figure IX-2. The broken line shows the

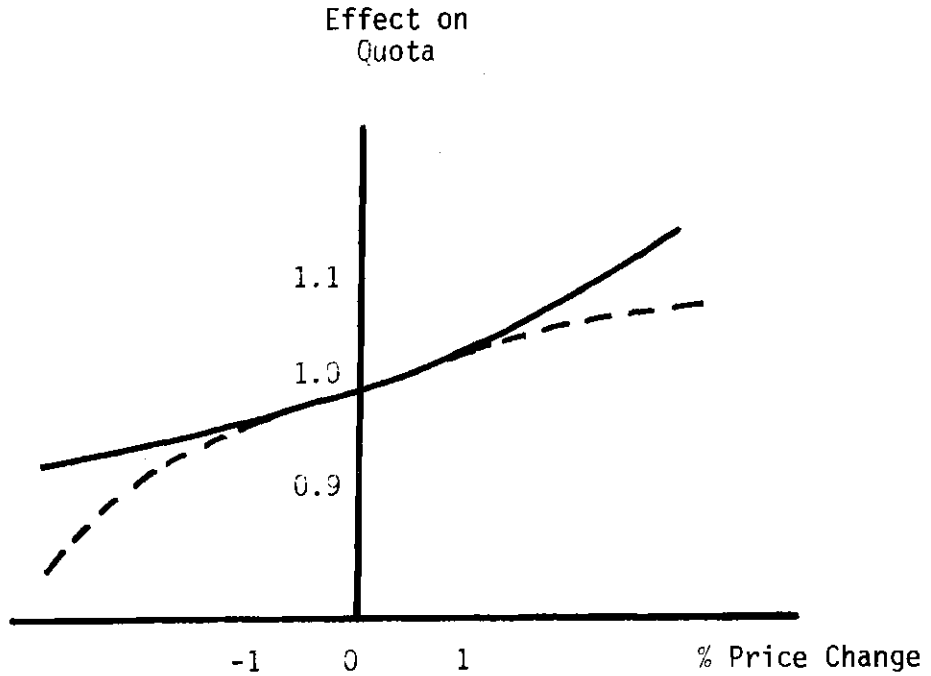


Figure IX-2. Effectiveness of Pacted Quotas.

'theoretical' effect on the pacted quotas due to a fractional price change. The solid line on the other hand, displays the actual effective quota to the market. The two lines deviate from each other at their extremes in response to quota defaults.

The quantity supplied at the market place is then given by the following expressions:

$$\text{Quota} = Q_1(P) \times Q_2(\Delta P) \quad (a)$$

where  $Q_1(P)$  and  $Q_2(\Delta P)$  are the two relations depicted by Figures IX-1 and IX-2 respectively and,

$$\text{Quantity Supplied} = \text{Quantity-to-Export} \times \text{Quota} \quad (\text{b})$$

where Quantity-to-Export is equal to the annual exportable production plus or less a fraction of the difference between the current producers' stocks and the desired stock value, i. e.,

$$\text{Quantity-to-Export} = \text{Exportable Production} + \frac{\text{Stocks} - \text{desired level}}{\text{PCT}} \quad (\text{c})$$

and PCT is the Producer-Correction-Time, the period of time required to drive stocks to its desired (target) value, (PCT = 1 year). See Chapter VII, expression (a).

Figure IX-3 exhibits the effect on behavior had the quota policy been institutionalized since the beginning of the century. Prices still exhibit the same unstable performance and combination of cyclic patterns as in the simulation runs exhibited in Chapter VII; nevertheless, stocks tend to fluctuate with more violence than before.

The reason for such behavior lies in the nature of the export-quota policy (loop P10) and also on the way it interacts with the structure of DWCM. When supplies are curtailed from the market place, the rate at which prices fall may initially be reduced. Further application of the quota policy may even support prices to a level high enough to promote more coffee acreage expansion than it would otherwise Rowe [29, p. 187]. The wider unstability of stocks is then the result of two combined effects: one during the short run, the other over a longer period. First, the enforcement of the quota policy creates larger stocks; second

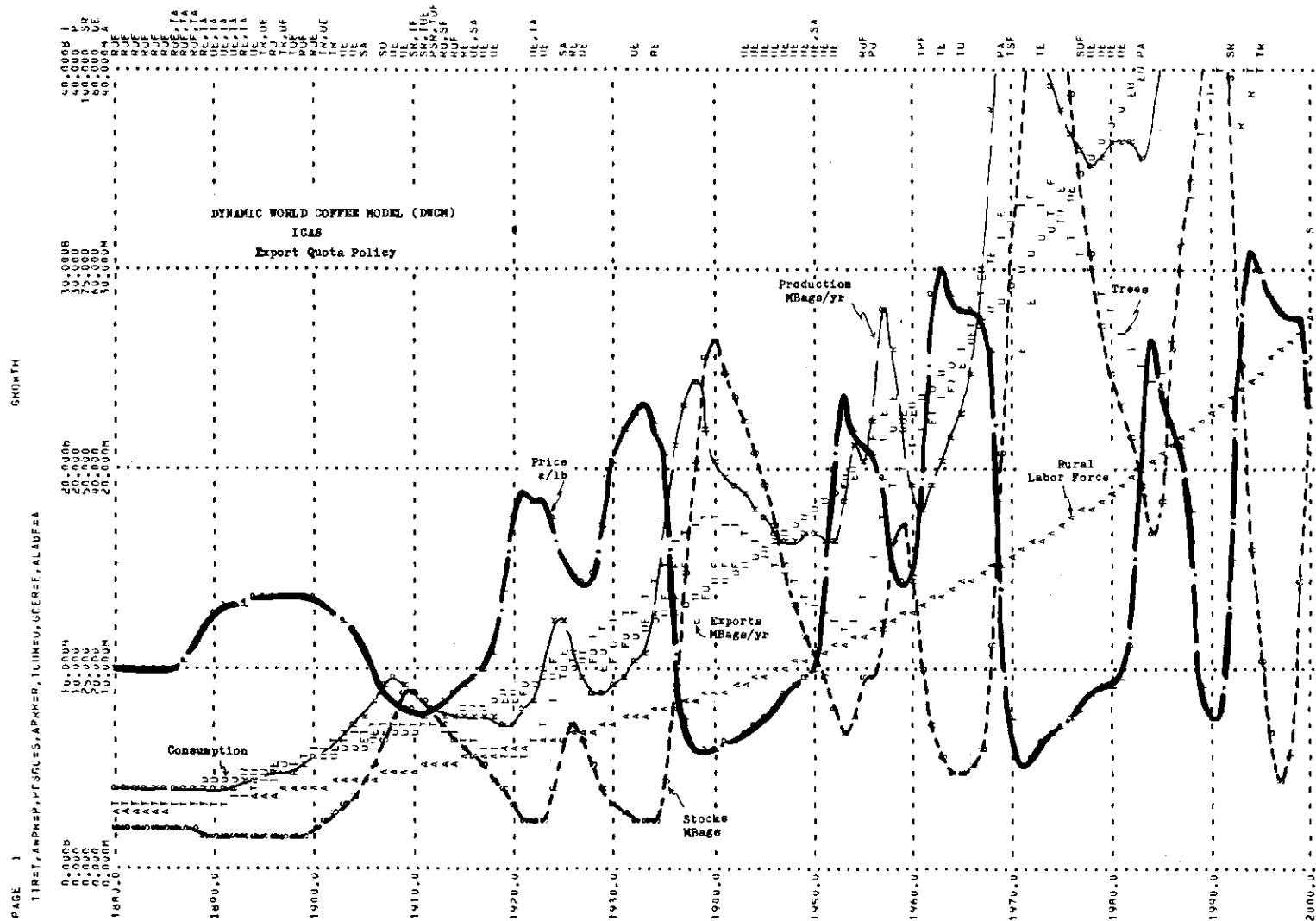


Figure IX-3. Effect of ICA.



the acreage expansion induces higher production rates and larger inventories several years later when the newly planted trees reach maturity. In fact, the main effect of the quota policy is to amplify the response due to the main production loops P1 (Labor) and P2 (prices), but it does not reduce the cyclic behavior generated by these two feedback structures.

## 2. Effect of a Buffer Stock Policy

A traditional alternative to export quotas is a buffer stock policy. A buffer stock policy consists in the creation of an international agency to regulate the flow of supplies to the market place. When prices fall the agency will purchase the surplus output to counteract a further price increase; the buffer stock then rises. On the other hand, when prices increase, the stocks are released to the market with the purpose of augmenting the available supplies and thus reducing any further growth in prices. This section shows that the creation of an international buffer stock does not promote the price stability it intends to achieve. On the contrary, the section shows that a buffer stock policy is apt to generate wider price oscillations and instability.

Figure IV-4 exhibits the structure of a possible buffer stock policy. In this case, producers still maintain a large control on the newly created buffer.<sup>3)</sup> The operation of the policy follows from the feedback loops in the diagram. When

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<sup>3)</sup> There are several variations to the buffer policy postulated here: the buffer could be primarily administered and controlled by either producers or consumers. Further, whether the buffer agency should directly sell to consumers or not is indeed a sensitive issue in coffee policy. All of these aspects among others, will require a different formulation of the buffer policy tested here.

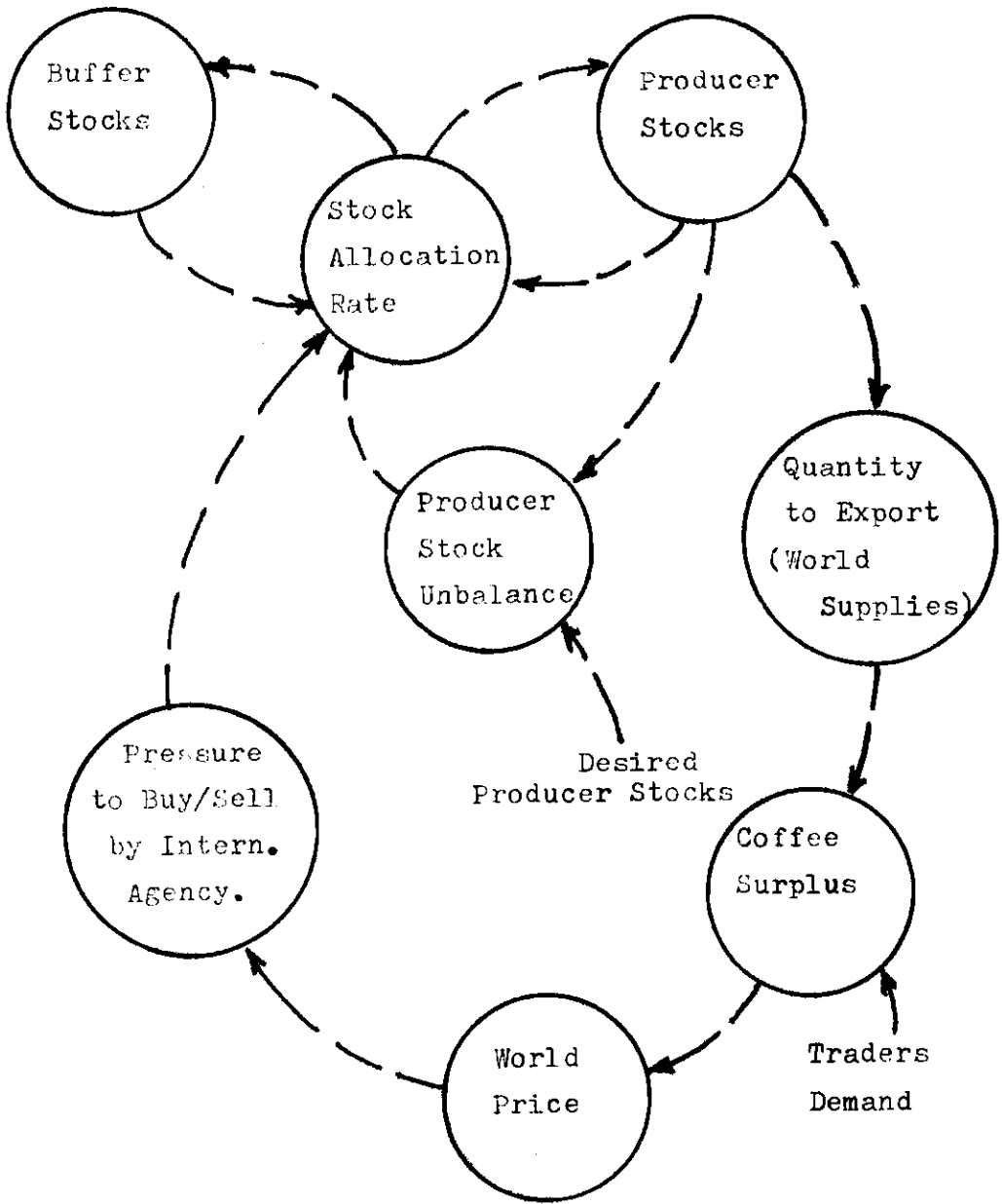


Figure IX-4. Buffer Stock Policy.

producers are overstocked and prices fall, the International Agency will buy a portion of their stock excess. Therefore, the Quantity-to-Export (world supplies) decays and prices may recover. When prices rise and the producers are with tight inventories, the Agency will release a portion of their stocks to the producers, thereby augmenting the Quantity-to-Export which creates higher supplies and a negative effect on prices.

Figure IX-5 presents the behavior of the above policy. The price wave exhibits a similar amplitude as in the case of the quota-policy; the major difference however, is that the six year cycle plays now a major role; hence, the effect of a buffer stock policy is to create even more unstability than a quota policy.

The amplification of the six year cycle results from the interaction of the new feedback loop P11 in Figure IX-4 with the loop structures T1 and T2 in the Trade and Distribution Sector. Assume prices are falling; thus production rates and producer stocks tend to be high and rising. At the same time traders are reducing their coverage (Loop T1) and also their purchases (Loop T2). Gradually, producer stocks will rise above the established desired value; then a portion of the surplus inventories will pass to enlarge the buffer stock (Loop P11). Hence, the Quantity-to-Export, i.e. supplies, tends to fall (expression (c) in Quota Policy). Prices then will not fall as fast as initially (Loop P2) which result in a larger desired traders coverage (Loop T1). In turn, a rising coverage requires an additional amount of imports; therefore, traders' demand rises while producer stocks will tend to fall. This situation creates a market with tight supplies. Prices then will rise. Similarly, producer stocks will gradually fall below the

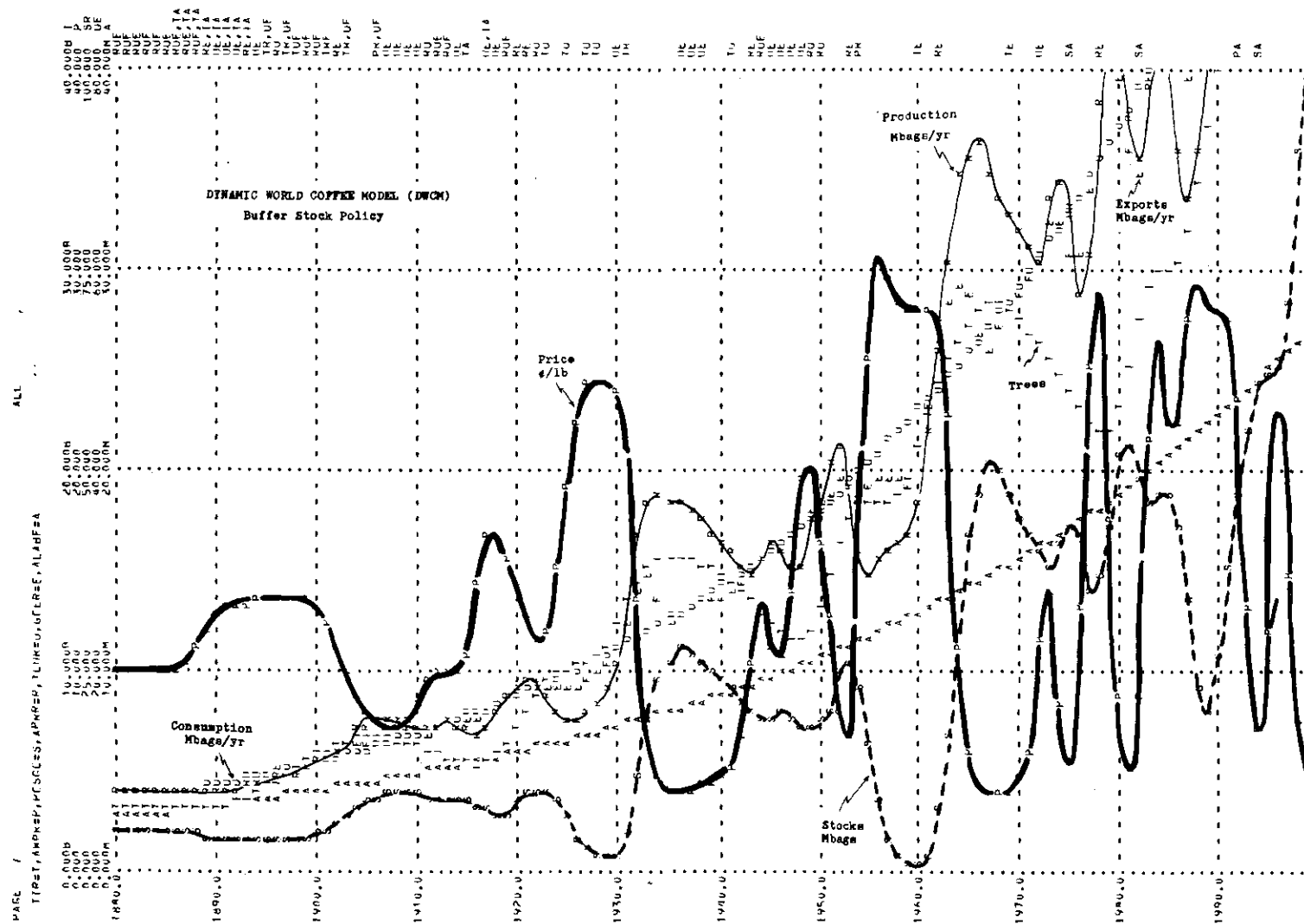


Figure IX-5. Effect on One Possible Stock Buffer Policy.

established desired level. At this time, additional quantities are released from the buffer stock, world supplies will tend to rise to counterbalance the previous period with rising prices. A new six year cycle is ready to begin.

Figure IX-5 still exhibits the long cycle of 32 years plus the harmonics movements generated by the production loops (P1 to P9). Clearly, the buffer stock policy in loop P11 does not produce any change on the basic relationships depicted by the production feedback loops; these loops cause the complex wave of 32 years plus its harmonics. Therefore, solutions to produce stability of this major movement require a direct effect on this structure, not the indirect and unfavorable effects provided by the buffer policy postulated here.

#### B. A New Proposed Stabilization Policy

The DWCM exhibits persistent cycles and unstable behavior under different conditions; this results from the operation of the basic structures embodied within the coffee market. Both the parameter testing in Chapter VII and the application of policy in this chapter provide evidence that a change in the behavior of the World Coffee Economy is possible only when the dominant effect of the feedback structures in the system are reduced.<sup>4)</sup>

This research has found that the major cycle of 32 years is caused by the operation of loops P1 (Labor - Planting Rate - Trees - Production - Income to Farmers - Labor), and P2 (Supplies-Price-Planting Rate - Trees - Production -

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<sup>4)</sup>The dominant effect of loops in a feedback is frequently referred to as the 'gain of the loop'.

Stocks - Supplies). Furthermore, the amount of supplies at the market place is given by

$$\begin{aligned} \text{Quantity-to-Export} = & \text{Production Rate} - \text{Domestic Consumption} \\ & + \frac{\text{Producer Stocks} - \text{Desired Stock Level}}{\text{PCT}} \end{aligned} \quad (c)$$

and the 32 year cycle appears in the behavior of production rates, stocks and prices, variables embodied in both loops P1 and P2.

A way to reduce the dominant effect, i.e. the gain, of the production loops P1 and P2 is to transform expression (c). In fact, if production rates are to be driven near current world consumption, the amount supplied at the market place ought to be a function of demand, not output. Furthermore, to avoid the presence of unstability originated in the Coffee Trade Sector, demand refers to end consumption, not to traders' demand. Hence, a new policy statement to regulate the annual amount of world supplies can be formulated as follows:

$$\text{Quantity-to-Export} = \text{Consumption Rate} + \frac{\text{Producer Stocks} - \text{Desired Stock Level}}{\text{PCT}} \quad (d)$$

where consumption rate is the annual amount of equivalent green coffee which each year is used to brew drinkable coffee.<sup>5)</sup> In addition, one effect of expression (d) is to omit the unstability caused by the production rates. The time to adjust the producer stocks to its desired value (PCT = 1 or 2 years) is a too short period.

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<sup>5)</sup> Consumption Rate in (d) is the variable used as an input in the DWCM.

When the DWCM was simulated with the new policy in (d) and with a correction time of 2 years, the system still shows wide unstability. The reason is that the additional amount of supplies caused by the stock adjusting term is large enough to promote a rapid price change; this in turn, stimulates the functioning of the production loops P1 and P2 to generate the long cyclic movements.

Figure IX-6 displays the behavior of the new policy when the Producer Correction Time is made sufficiently long to smooth the effect of over or under stocks on world supplies (PCT = 30). Note that the Traders Correction Time, the period used by traders to adjust their stocks to their desired target, remains unchanged (TCT = 0.5 years). The figure shows the effect of the policy had it been institutionalized since the beginning of the century. The simulated run does not exhibit a 32 year cycle or any of its major harmonics; also until the year 1970 the behavior of prices is rather stable. Thereafter, however, the six year cycle displays rampant fluctuations.

The application of the new policy did not alter any of the feedback loops of the Coffee Trade Sector; hence nothing has been done to prevent the appearance of the six year cycle. A way to reduce the unstable performance of this type of cycle is to augment the Traders Correction Time from its normal value of 0.5 years to say, 6 years. With this change the new policy transforms into:

#### World Supplies

$$*Quantity\text{-}to\text{-}Export = Average\ Consumption +$$

$$\frac{Producer\ Stocks - Demand\ Stock\ Level}{PCT}$$

$$PCT = 30\ years$$





Traders Demand<sup>6)</sup>

$$\begin{aligned} \text{Quantity-to-Import} &= \text{Average Consumption} \\ &+ \frac{\text{Desired Traders Stocks} - \text{Trader Stocks}}{\text{TCT}} \end{aligned}$$

TCT = 6 years.

Figure IX-7 displays the stabilization effect of the new policy. Prices gradually grow in a stable manner, and export rates stay almost in balance with consumption.<sup>7)</sup>

This policy does not produce a total stable system however; stocks still exhibit a long cycle of about 40 years although the amplitude of the wave tends to be smaller than before. In turn, the behavior of both the tree-capacity and production rates also shows a similar wave pattern, a cycle difficult to observe in the figure.

The cause of the improved performance of the DWCM under the new policy lies primarily on the effect the policy has on the bargaining process between producers and traders to establish sales and price (loops P4 and T2). With the new policy, both the Quantity-to-Export (Supplies) and the Quantity-to-Import (Traders' demand) contain a common term: the average consumption. Therefore, the amount of surplus (the difference between supply and demand) at the market place tends to be much lower than before. Hence, prices will not respond as fast as

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<sup>6)</sup>Chapter VI.

<sup>7)</sup>Export (E) and consumption Rates (U) are both plotted on the same scale, from 0 to 80 million bags/year. Production rates (R) and Stocks (S) are both plotted on a scale of 0 to 100 million bags/year and bags respectively.

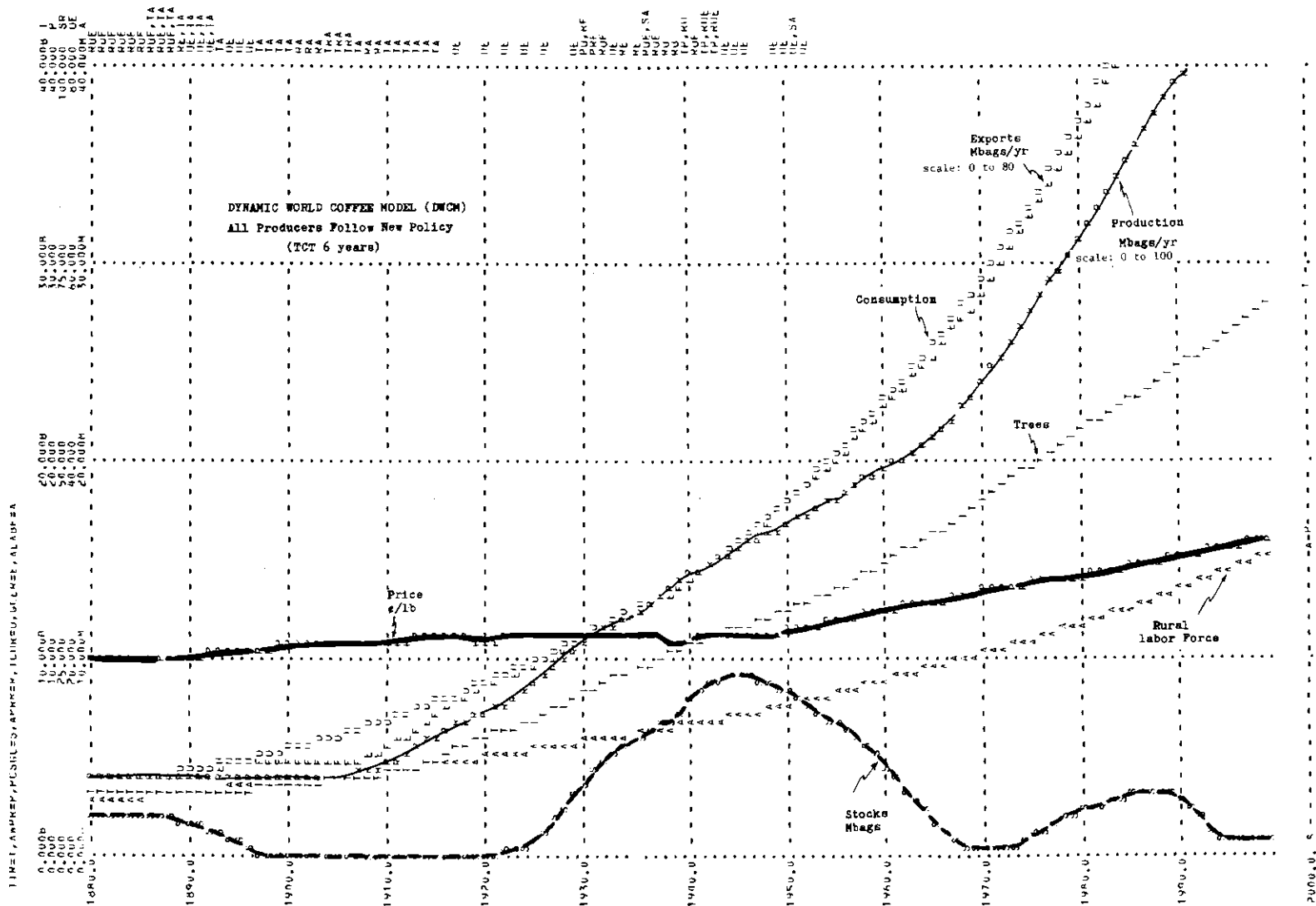


Figure IX-7. Behavior with New Policy (TCT = 6).

in the previous runs.

The next two figures display the effect on behavior when Brazil the largest producer with about 35% of the market share, implements the new policy while the smaller producers follow the traditional supply policy with a long correction time ( $PCT = 30$ ). Figure IX-8 assumes a Brazilian market share of 35%; Figure IX-9 on the other hand assumes a larger market share (50%) for the same country. The DWCM still shows an improved performance over the previous policies.

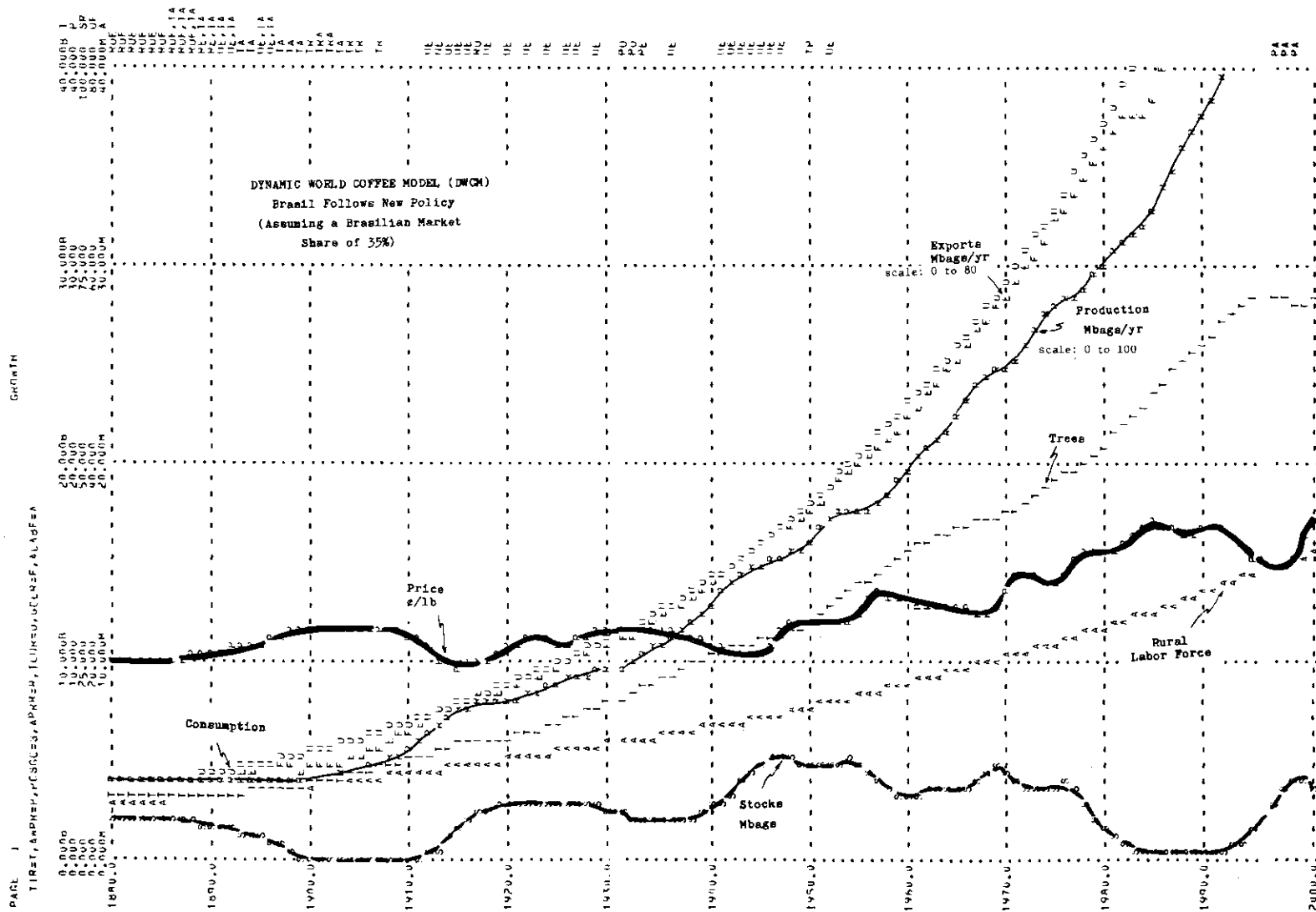


Figure IX-8. Brazil Follows New Policy (Market Share 35%).

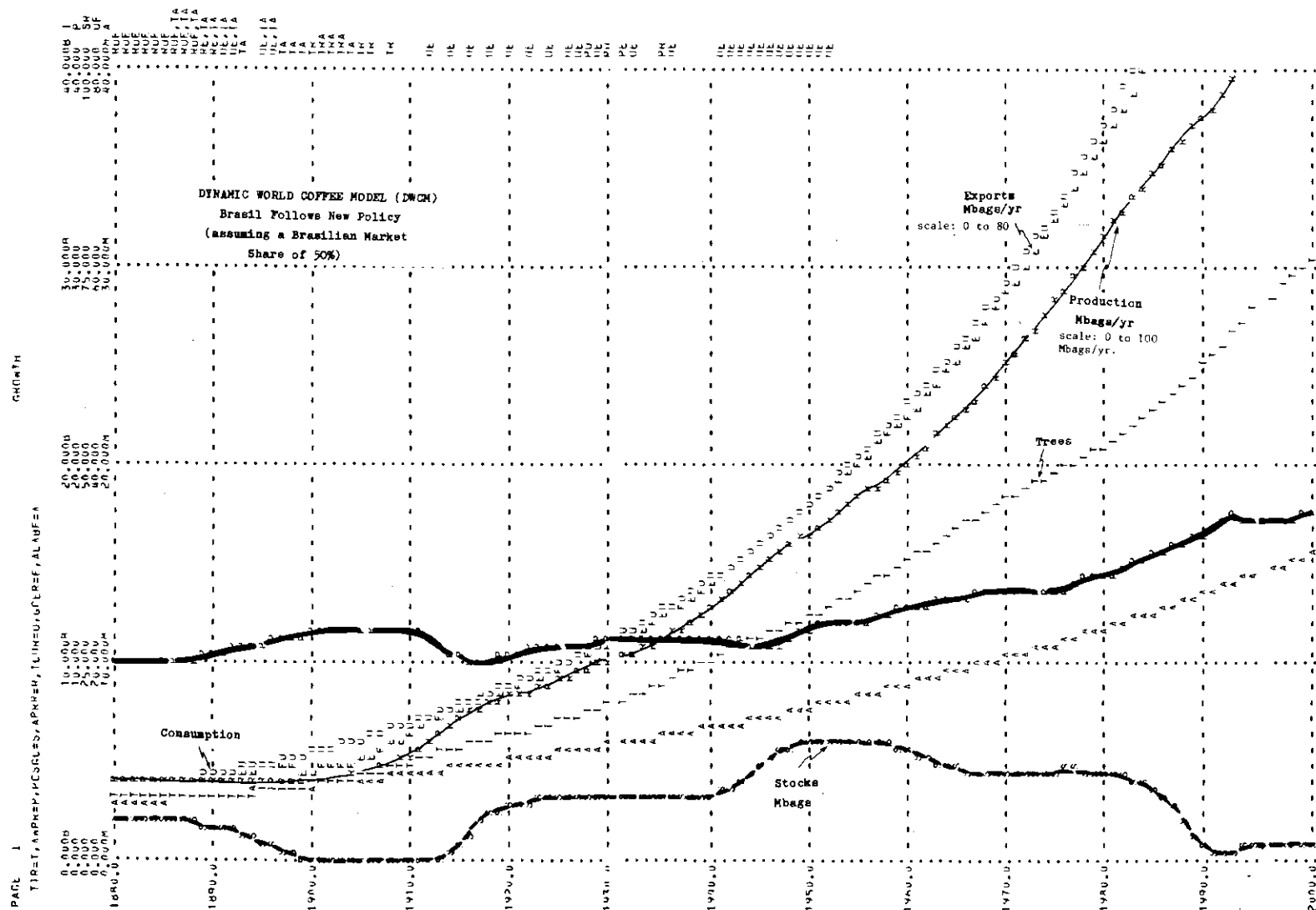


Figure IX-9. Brazil Follows New Policy (Market Share 50%).

## CHAPTER X

### CONCLUSIONS AND RECOMMENDATIONS

#### A. Conclusions

##### 1. The Coffee Cycles (Chapter IV)

The cyclic behavior of the World Coffee Economy has been a subject of controversy and contradiction. This research presents evidence that the behavior of the coffee industry displays a combination of intertwined cyclic movements of different period. Analysis performed on the behavioral patterns of both the annual coffee prices (1825 to 1973) and yearly production rates (1850 to 1973) rendered the following results:

- (a) Long-Run 32 Year Cycle. This is a long cycle of around 32 years in duration. The cycle contains a lagged harmonic whose period is 16 years. Furthermore, this long-run movement contains several minor harmonics of shorter duration: 8, 4 and 2 years respectively.
- (b) Intermediate-Range 6 year Cycle. This is a minor cycle which combines with the above composite wave.
- (c) Short-Term Cycles: 3 and 2 years respectively. The analysis indicated the presence of two cycles of about 3.3 and 2.2 years in duration; the 3.3 year cycle has a stronger influence than the 2.2 year cycle.

When the above cyclic movements were grouped together into a mathematical expression to rebuild the world (real) coffee price series since 1880, the

estimated series exhibited remarkable similarities to the actual coffee price pattern. In fact, both series displayed a similar shape and number of peaks, and the amplitudes and values of the two series approximate each other.

(Figure IV- 8 ).

## 2. Nature of the Coffee Cycles and Price Unstability

### a. The World Coffee Production Sector and the 32 Year Cycle (Chapter V).

The structure of the World Coffee Production sector postulated in this research consists of ten coupled feedback loops. Four of these (loops P1 to P4) form the main structure of the sector; their operation generates unstable oscillations of  $32 \pm$  years in duration. These four loops describe the effects of labor supply and world price on land expansion and planting rates. Further, the same loops describe the effects of additional tree capacity on production rates and stocks; on price formation and income to the farmers; and together they explain how these variables interrelate to attract more or less labor to coffee regions.

The length of the 32 year cycle is caused by a long sequence of delays embodied within the adjusting mechanisms of the main loops and which were not clearly recognized in earlier coffee studies. Some of these delays are the following (Table V-1, Chapter V).

- (1) Time to adjust land to a desired acreage
- (2) Time to prepare the newly added land
- (3) Time to plant additional available acreage
- (4) Tree maturing delay
- (5) Time required to distribute the current production rates

- (6) Time to average current quoted world prices
- (7) Time to adjust/enforce domestic price policy
- (8) Time to average current domestic prices to the farmer
- (9) Time to perceive a change in farmers' income and standard of living
- (10) Time required to attract labor to coffee regions
- (1) Time to adjust land to a desired acreage (as (1) above)

Each one of the above time delays involves a duration of at least one or two years. The maturing delay of four or five years is just one delay among many.

Loops P5 to P10 are secondary loops within the coffee production sector. Their operation causes the presence of harmonics of shorter duration which combine together to shape a complex wave of 32 years of period. In particular, the fact that older coffee trees are abandoned as prices fall (loop P5) causes a lagged harmonic of around 16 years' duration. Similarly, the tendency of farmers to upgrade their cultivation procedures when prices rise (loop P8) introduces an additional harmonic whose period is about 8 years.

One of the effects of advances in agricultural coffee technology is to develop more productive seeds. An undesired byproduct of this technological process is to accelerate the obsolescence of the more matured trees (loops P6 and P7); the research shows how rapid tree obsolescence rates produce higher order harmonics which combine with the 32 year wave; more importantly, this type of "technologically induced obsolescence" tends to add instability to the behavior of prices.



b. The Coffee Trade Sector and the Six Year Coffee Cycle (Chapter VI).

The Coffee Trade Sector contains two major subsystems: The Trade-and-Distribution Sector and the Future Market Sector. The Trade-and-Distribution Sector involves two coupled feedback loops, one to replenish and maintain inventories near a target value (loop T2), the other to adjust traders' inventory targets in response to expected price changes (loop T1). The operation of these two loops exhibits a stable cycle whose period is about 4.8 years.

The Future-Market Sector contains four coupled feedback structures (loops T3 to T7). Some of these describe the behavior of hedgers and speculators in the future market (loops T4, T5 and %6); others function to interlock this market with the Trade and Distribution sector (loops T3 and T6). When the two sectors are linked together the behavior of the system turns out unstable and the period of the cycle increases to near six years in duration.

Despite the unstabilizing effect on the Coffee Trade Sector, the futures market renders a benefit to both traders and users of green coffee. In fact, a user who routinely maintains a short position in futures is able to operate with a lower average level of inventory investment.

c. Coffee and the Three and Two Year Cycles. This research does not study the nature of these two short movements. The two year cycle may reflect the biological cycle of the coffee tree, as claimed by most authors. The three year coffee cycle (3.3 years) encountered in this research presents an interesting and intriguing problem, however. History on coffee economy does not attest the existence of such a type of movement. Yet, there exist a chance of about

95% that this cycle is not the result of random events.

### 3. The Dynamic World Coffee Model (DWCM) (Chapter VII)

The Dynamic World Coffee Model (DWCM) postulated in this research couples together the Coffee Production and Trade sectors. The behavior of the model exhibits both the long cycle(s) originated by the production sector, and the six year cycle generated by the trade sector.

The DWCM exhibits the unstable characteristics displayed by the actual behavior of the coffee market (Chapter II):

- (a) Prices, production rates and producer stocks display a composite wave of about 32 years in duration. The amplitude of the wave tends to widen throughout time.
- (b) The widening peaks are more prominent in the case of the producer stocks. Stocks tend to grow rapidly, reach about one year of supply and then decay. A price recovery occurs when stocks have fallen to abnormally low values.
- (c) Stocks peak about ten years later than prices and about six years later than production.
- (d) The shape of the simulated price and stock patterns exhibits remarkable similitude with the actual pattern of behavior of these two variables in the world coffee market.

### 4. Price Instability and Policy

Simulation runs of the model indicate that the following structural characteristics of the World Coffee Economy are responsible for the unstable performance exhibited by the coffee market.

(a) Producers Supply Policy. Chapter IX on World Coffee Policy showed that a supply policy based on exportable production rates and rapid stock adjustment produces unstable cycles of 32 years.

(b) Traders Demand Policy. The same chapter shows that the unstable trade cycle of 6 years can be stabilized by augmenting the period of time during which traders adjust their stocks to the desired target value.

(c) Stock Policy of Small Producers. Chapter VII presents evidence that the stock policy followed by the small producers tends to cause wider price fluctuations than the stock policy of a large producer.

(d) Induced Tree Obsolescence. The development of new types of seed with high yields per tree induces large tree obsolescence rates. Rapid accumulation of obsolete capacity produces an additional effect on price instability (Chapter V).

(e) Labor Supply. The Coffee system is sensitive to changes in the rate at which the available labor force grows. A reduction in the percent rate the producer nations' population growth tends to reduce the amplitude of the price wave (Chapter VII).

##### 5. Effect of Traditionally Recommended Stabilization Policies (Chapter IX)

(a) Export Quota Policy (ICAS). This research presents evidence that systems of export quotas like those traditionally used in the previous ICAs do not produce a major effect on the unstable performance of the World coffee economy over the long range.

(b) Buffer Stock Policy. Preliminary research on a buffer stock

policy indicates that an internationally administered buffer stock does not produce its intended stabilization effect. On the contrary, it appears from this research that the establishment of this type of policy may even add more instability to the long run performance of the World Coffee Economy.

## 6. Stabilization Policy

This research shows that a major change in the producers supply policy produces a more stable performance of the World Coffee Economy. The new supply policy is given by the following expression:

$$\begin{aligned} \text{World Supplies} = & \text{Average (End) Consumption} \\ & + \frac{\text{Producer Stocks} - \text{Desired Stock Level}}{\text{Producer Stock Correction Time}} \end{aligned}$$

where consumption means the annual rate of coffee usage by the end customers; the Producer Stock Correction Time is the time required to adjust stocks to their desired value. In the new policy this period of time is made very long, about 30 years.

The above policy presents two important differences with respect to the current policy used by producers. One, the amount supplied at the market place depends on end consumption, not on exportable production. Second, although the stock adjustment term remains unchanged, the new policy requires the implementation of a very slow and gradual stock adjustment process, as opposed to the current policy in which stocks tend to be driven to the desired value over a too short period of time, one or two years.

The new policy diminishes the instability of the 32 year cycle and its harmonics. To reduce the unstable performance of the 6 year cycle, the demand policy used by traders requires also the application of a slower adjusting stock mechanism.

### B. Recommendations

1. Although the new policy constructed in this research produced a far more stable response than the other policies tested, the author of this research recognizes that several problems remain to be solved before a definite recommendation can be given in regard to the benefits brought about by the new policy. The following is a short and incomplete list of some of the main issues that require further investigation:
  - a. Effect of parameter sensitivity on the new policy.
  - b. The new policy as a type of International Coffee Agreement: (i) producers; (ii) producers and consumers.
  - c. Market share required by a larger producer(s) in order to stabilize the market. In this case small producers would be assumed to follow the traditional supply policy.
  - d. The stabilization effect of the new policy, or any other for that matter, depends on the actual position of the coffee cycle at the moment of implementing it. The proper question is then, should the new policy be introduced when prices are high or low?
  - e. Stabilization of the six year coffee trade cycle requires further

investigation of the future market. Implementation of the new policy requires the establishment of several arrangements between producers and consumers.

2. The Dynamic World Coffee Model (DWCM) postulated in this research could be extended and redesigned to test in detail the following aspects of the World Coffee Economy:
  - a. Behavior of small producers versus the behavior of the large producers.  
This would require the addition into the model of complete sectors representing both the small and the large producers.
  - b. Behavior of the Mild, Arabic and Robusta producers and the effects of price differentials and producers competition on the coffee cycles.
3. If a new stabilization policy is not implemented, the model extension(s) suggested above will allow designing individual producer policies to stabilize income or increase market share in the face of world coffee instability.  
In particular:
  - a. 'Best' policy of the largest producer, i.e., Brazil, in the face of an unstable market.
  - b. 'Best' policy of the small producers, i.e., Colombia or the Central American nations.
4. The trade and distribution sector could be extended to investigate similar questions at the trade and processor levels. If several competitors are included, the model will allow testing the goodness of individual policies with the purpose to establish the best course of action to achieve further

market penetration and growth.

### C. Recommendations for Futher Research

Most assertions in the coffee model postulated in this research have been supported by factual evidence, cited literature or obvious logic. In several situations, however, the author did not find bibliographical references or hard data to support the postulated relationships. Additional research is required to assess the veracity of both the logic and conclusions upon which these relationships are founded. Table X-1 lists the assumptions made in the DWCM which require further investigation.

Table X-1. Assumptions in DWCM Which Require  
Further Investigation

<u>Sector</u>	<u>Chapter</u>	<u>Appendix</u>	<u>Section</u>	<u>Suggested References if any</u>
1. Production Sector	V	B-I		
a. Induced Obsolescence			13	
b. Abandoned Fraction of Trees			15	[1]
c. Effect of Prices/Income on Removal of Obsolete Trees			14	[1]
e. Foreign Cash Reserve and Stock policy			18	

Table X-1 (Continued). Assumptions in DWCM Which Require  
Further Investigation

<u>Sector</u>	<u>Chapter</u>	<u>Appendix</u>	<u>Section</u>	<u>Suggested References if any</u>
2. Trade Sector	VI.	BII		
a. Trade and Distribution				
1. Qualification of Supply of Storage Function for Coffee			3	[45]
b. Futures Market				
1. Long/Short positions in response to price/ basis change			11, 12	
2. Intended sales-purchases and price formation			4	
3. Pressure to sell distant futures over next futures and market inversion			4	[14], [18]
4. Behavior of open interest at the coffee exchanges			6	[14], [18]



APPENDIX A  
LITERATURE SURVEY

1. Coffee
2. Commodities in General

## LITERATURE SURVEY

### A. Coffee

#### 1. Rowe's Study on Coffee

Rowe [24, 25] considers that the best solution to the problem of recurrent overcapacity and coffee price instability is to return to an unregulated market. Nevertheless, the present conditions of the coffee market require the creation of an international agreement of some sort with the purpose of achieving a gradual transition from the current state to one with no controls.

The International Coffee Agreement (ICA) is an effective process for controlling prices to meet the producer countries' needs. Consequently, the ICA provides a subsidy to high cost producers while at the same time prevents a downward price adjustment toward genuine costs of production. For this reason Rowe foresees a general stagnation in the development of higher productive techniques, a development which would hinder both the expansion of low cost coffee plantations and the removal of obsolete capacity--a situation not compatible with a real long run equilibrium. Furthermore, these type of agreements have the adverse effect of postponing the implementation of sound economic solutions to the coffee industry and make the application of corrective policies difficult to put into effect, in view of the well entrenched interests generated during the ICA period.

Although one of the aims of the ICA is the adjustment of production to

meet demand, the controls to regulate surplus stocks and productive capacity have been traditionally vague. These controls to be effective enough would require the use of massive financial assistance which must come from abroad, a plan not included in the 1962 agreement, although established six years later.

Rowe believes that international controls should still exist to drive the present coffee economy into a state of pure competition and long run equilibrium between demand and supply. This approach, which will allow a gradual transition, should permit producers to adjust its necessities to lower levels of coffee income, while at the same time an international fund or arrangement of some sort will help to switch resources to more productive activities. Nevertheless, Rowe insists, the basic principle which any control scheme must contain is allowance for a 'decline of the price level down to the true equilibrium level of supply of demand.' Thus, he considered as economically sound one of the first proposals from the Coffee Study Group of the United Nations in 1961 which contained gradual reductions in annual coffee prices, and the establishment of an international system of buffer stocks to keep prices within certain limits. Both conditions were unacceptable to most producer nations.

V. D. Wickizer [28] is one of the authors who has studied the coffee economy. He has developed additional criticism of the regulatory schemes provided by the International Coffee Agreements, and has presented comments similar to those made by Rowe. In particular he has concentrated on explaining the political motivation behind the ICAs and has analyzed the major obstacles faced by producers and consumers when trying to enforce most of the controls existing

within the agreement. Unfortunately, limitations of this thesis do not permit further explanation of Wickizer's work. Reference [ 28 ] presents a summary of the criticism he developed previously in several other papers.

## 2. Geer's Study on Coffee

Thomas Geer [13 ] has studied the world coffee economy within the framework of the theory of oligopolistic competition. He has concluded that the world coffee industry can best be represented by a bilateral oligopolistic model with product differentiation on the production side, and by an oligopsonist model on the buying side. The normal performance of this type of market is characterized by instability, rather than stability and long-run equilibrium, as it would be were the coffee market a pure competitive market. Therefore, he advocates the need to consider this market as an 'exception' in which appropriate regulatory controls should be imposed to drive the system toward a stable performance.

Geer analyzed the behavior of prices from 1945 to 1960. He concluded that the price unstability over the period was the result of non-collusive strategies followed by the producer countries. In turn, the non-collusive strategy of oligopolists acting on a differentiated market makes it increasingly difficult for one oligopolist to establish a regular pattern or reaction when faced by competitors' price changes. As a result, every one of the independent sellers confront a widely undeterminate and fluctuating demand for his produce under some conditions. This situation may produce price stability at some indeterminate level, although more often than not it will tend to create chaotic price fluctuations in which a long run equilibrium cannot be reached--a situation which he names indeterminate

instability.

This performance requires therefore, some form of collusion among producers, collusion which must take the form of a restriction of the freedom of all oligopolists to use independent market strategies. This need for collusion among producers, in order to diminish the state of indeterminate instability, is one of the reasons to implement prices and output controls as a first step to get a more 'competitive' and stable type of behavior.

Geer considers the International Coffee Agreements of 1962 and 1968 as efficient and successful ways to establish a policy of collusion among suppliers. Their major benefit however, has been to prevent price fluctuations created by oligopolistic price wars. He notes that short term price fluctuations during the ICAS' period have been reduced from 12.4% to 6.9% per year.

### 3. Arak's Study on Brazilian Coffee Growers

The decision process of the Sao Paulo coffee growers with respect to planting, removal of old capacity and crop abandonment has been studied by Arak [1].

The decision to plant a certain number of trees each year, depends on the difference between a desired planted acreage and the current acreage planted with coffee trees. In turn, Arak postulated that the speed at which usable land is conditioned to plant coffee is proportional to the percentage of trees which are old; also, if the average yield of the tree stock is relatively low the farmer will tend to plant new productive trees to renovate his plantation.

The removal decision is based upon a different process than the planting

decision. Arak postulated that the number of trees removed each year is a function of the expectations of both price and physical yield, where the average yield of a plantation depends on the average age of the trees and also on the fertility of the soil [1, p. 216].

An abandoned tree is one which remains standing up but which is not cultivated. As the tree ages, its yield and revenue declines while the cost of harvesting and cultivating the tree increases. Therefore, the farmer will not cultivate those trees whose annual revenue is less than its maintenance cost. From this argument Arak concluded that the older the trees at which abandonment takes place, the smaller the percentage of older trees abandoned [1, p. 216-217].

Arak used the above set of hypothesis to test the price responsiveness of the Sao Pablo Coffee growers. The linearized statistical model rendered acceptable explanation for the performance of the coffee growers during the years studied. The World Coffee Dynamic Model proposed in this thesis makes use of several of the concepts developed by Arak.

#### 4. Other Studies on Coffee

The performance of the coffee market under the International Coffee Agreement has been analyzed in several investigations sponsored by the United Nations, the International Bank, the International Monetary Fund, and other worldwide organizations [5, 6, 16, 27]. These studies generally present a large body of factual data and concentrate on exploring the feasible application of regulatory controls and their effects on domestic developmental policies.

Modeling and statistical experimentation on coffee have recently received attention by various authors. Wickens et al. [27] have constructed a coffee model which explains the import demand for each type of coffee bean. They have assumed that the demand for the coffee produced by a particular country varies in relation to the prices of four substitutable bean varieties. The research shows that consumption of coffee may not follow the classical demand theory and seems to be influenced by the inventory held by individual processors.

M. Epps [4] has built a simulation model of the world coffee economy to determine market outcomes based on possible changes in the terms of the International Coffee Agreement. The model consists of fifteen equations which taken together represent the world market viewed as an oligopoly with product differentiation. The research estimated the foreign income receipts at different levels of Brazilian support prices and export quotas assuming several production goals for each one of the producers of Brazilian, Mild and Robusta types of coffee. The simulation was run for the 1958 to 1965 period and the estimated equations were used to forecast the revenue outcomes during 1966 and 1967. Results of this study indicate that for all three export grades of coffee, the revenues vary in direct proportion with the support price; a price of 90¢ per pound yielding the largest revenues.

## B. Previous Research on Commodity Economic Systems:

### A Summary

To date, there exists no unified theory to explain the short, medium, and long term movements of commodity prices. There is, however, a broad spectrum

of statistical techniques which have been used to analyze direct open-loop relations among some of the variables which shape the commodity markets. These methodological approaches have followed the lines of the classical econometric theory with frequent use of auto-regressive models, time series analyses and more recently, spectral analysis. These applications have been used to test the performance of the variable trends during medium and short periods and also in studying the random nature of short term price fluctuations.

#### 1. Short Term Price Fluctuations: Studies by Working, Larson, and Brinegar

A number of different theories have been proposed to explain the nature of commodity price behavior. Among these, the theory of anticipatory price formation by H. Working [46], has received major attention during the last years. Working hypothesized that the erratic price behavior observed in most commodities is the result of randomly appearing information in regard to the future states of the demand and supply for the product. Thus, the price of futures in a commodity is the result of anticipated expectations about the future, and not the effect of current changes in output and consumption. To confirm his theory, Working found no positive or negative correlation between two successive price changes, which indicates that short term price movements for the commodities studied may follow a random walk.

The previous theory has been partially confirmed by Larson [42] and Brinegar [37], who found evidence of low positive or negative correlation in price changes when studying the same group of U.S. domestic products.



## 2. Short Term Systematic Behavior: Studies by Houthacker and Others

The presence of systematic price behavior has been confirmed to some extent by the works of Houthacker [39], Smidt [44], Alexander [34] and others. They have observed the profits or losses resulting when trading procedures are applied in a consistent fashion. If the selected procedure, in response to a given price pattern, produces a profit over a long period of time, then past price movements can be successfully used to forecast future price changes. This means that price changes are not entirely independent. Authors following this methodology have generally suggested that the short term price formation of a commodity results from a combination of both a random walk pattern and a seasonal movement. However, they generally agree that the systematic component has less effect than the random component in explaining the variability of the price pattern of futures. A similar situation has been found for spot price movements [40, p. 98], although in this case the systematic component of prices seems to have a larger influence than in the case of the futures.

To date, none of the postulated theories explains satisfactorily the short term price movements exhibited by most agricultural commodities. Critics of the random walk theory generally note the weakness of the statistical procedures used to test the randomness of price changes. They note that under such tests systematic trends may look like random walks. On the other hand, some theorists claim that the very existence of speculative markets preclude the presence of predictable components of price behavior; a predictable pattern would attract a large number of profit-oriented trades whose effect is to add randomness to any

systematic pattern [40, p. 84]. Still, an opposite view indicates that, contrary to the purely speculative markets, the commodity market is made not only by profit-oriented traders but also by hedgers, processors whose primary motivation is to diminish their operating risk caused by fluctuation in their raw material, and who consequently do not seek profits; hence the existence of systematic behavior is possible. Further, supports of this view note that the presence of systematic price patterns result from the seasonal behavior exhibited by supply and demand, a seasonality also associated with periodic storage limitations.

Worth noting here is a remark made by Hauthacker [39] in regard to the nature of the short-term price movements of most commodities:

Commodity price developments are watched by relatively few traders, most of them quite set in their ways; even in the most active future markets the volume of serious research by participants seems to be quite small. It is therefore possible that systematic patterns will remain largely unknown for a very long time.

### 3. The Labys and Granger Studies

Perhaps the most complete statistical experimentation on the behavior of short term price movements has been conducted by Labys and Granger [40, 41]. Their investigation deals only with a group of commodities produced and traded on domestic U.S. markets, in particular, those featuring both cash and futures exchanges and having a fairly complete history of data and records on speculation and hedging. The authors have created a commodity price econometric model capable of both explanation and prediction of short term price behavior.

Labys and Granger have used spectral analyses to analyze daily, weekly, and monthly price movements of both cash and future price series. The

estimated power spectra suggests that the price pattern of all commodities studied has a strong random component, but some regularity has been discovered in the fluctuations of seasonal or longer duration.

The authors established the frequency components of the price patterns, then used these results to investigate the validity of Working's theory of expectations and its influence on price formation. To check this theory, they tested the hypothesis: "the future price is a good estimator of the expected spot price, once the future has matured." The cross-spectra between the futures and spot price time series rendered rather conflicting results, as coherence between the two series was found significant but the required lead-lag relation was non consistent. Therefore, the research was unable to prove or refute the expectations hypothesis. Nevertheless, the study brought into light several relations useful to predict price developments. Among these, Labys and Granger found that the best predictor of a future cash price is the current cash price, while near future prices were found to be more related to current cash price than were more distant futures.

One of the important conclusions provided by Labys and Granger's investigation deals with the role the simple price-quantity theory of demand plays in shaping longer run price regularities. In general, current supply and demand failed to provide adequate explanation for price movements while both hedging and speculating in the future market were found to have a larger influence in price formation than was previously recognized [40, p. 130].

The authors have also tested the influence of several other factors on prices. The results of these investigations were brought together by means of step-wise regression procedures. They found that price fluctuations are the result of prices of substitutable commodities, levels of hedging and speculating, the pressures of demand on supply, and business-cycle indicators, in that order [40, p. 36]. However, the effect of speculative influences tends to decline in importance as one considers a longer run, while the effect due to the business cycle becomes more relevant.

#### 4. Other Important Studies on Commodity Price Behavior

There are several authors who had investigated the nature of both intermediate and long-run commodity behavior. Traditionally, these researchers focus on the Keynesian concept of risk premium and develop variations of the supply of storage theory to explain intermediate type of movements while many other researchers have developed alternative formulations of the Cobweb form to explain long run behavior.

Cootner [38], Houthakker [39] and Working [46], among several others, have been leaders in the development of the Supply of Storage concept to explain medium range behavior. Later, Weymar [45] further elaborated on the theory and successfully tested it within the context of cocoa, an internationally traded commodity whose tree characteristics and market structure loosely resemble those of coffee. On the other hand, one of the best known conceptual models to explain long-run commodity behavior is perhaps the Dynamic Commodity Cycle Model (DCCM) developed by Meadows [43] in 1970. Both Weymar's cocoa model

and Meadows' DCCM are two important pieces of commodity research; in particular they form the starting point to build the World Coffee Dynamic Model presented in this research. For this reason, a more detailed review of these two studies appear within the main text of this thesis, in Chapter III.

## APPENDIX B-I

### A WORLD COFFEE MODEL

#### PRODUCTION SECTOR

(Description of Equations

Assumptions and Support)

## I. PRODUCTION SECTOR

### 1. Agricultural and Urban Labor Force (ALABF, ULABF)

The total number of individuals currently working or potentially employable within the agricultural and industrial sectors of the coffee-producing countries constitute the agricultural and urban labor force, respectively. The labor force in each one of these groups at the end of a year can be easily calculated from the previous year labor force population and the net growth and migration rates during the same year. Migration tends to restrain the growth in the agricultural labor force, while it compounds to create higher growth rates at most urban centers. <sup>1)</sup>

$$L \quad ALABF.K = ALABF.J + DT * (NGALF.JK - MTUC.JK) \quad (1)$$

$$N \quad ALABF = 3 * 10^6$$

$$L \quad ULABF.K = ULABF.J + DT * (MTUC.JK + NGULF.JK) \quad (2)$$

$$A \quad TALABF.K = ALABF.K + ULABF.K \quad (3)$$

- \* ALABF      - Agricultural Labor Force (men)
- NGALF     - Natural Growth Agricultural Labor Force (men/years)
- MTUC      - Migration rate to Urban Centers (men/year)
- \* ULABF     - Urban Labor Force (men)
- NGULF     - Natural Growth Urban Labor Force (men/year)
- \* TALABF    - Total Labor Force (men)

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<sup>1)</sup> In the coffee producer nations, population of urban centers has traditionally grown at faster rates than population in rural areas. In Latin America it is not uncommon to find cities with yearly growth of about 6%, a figure which is almost twice as large as the average population growth of these countries.

## 2. Labor Growth and Migration Rates--NGALF, NGULF, MTUC

The natural population growth of the coffee-producing countries generates a steady flow of individuals who want to enter the labor force and engage in productive life. A further increase in labor force normally brings about the formation of new families, and the raising of children who later, when mature enough will also enter the labor force. At the same time, elders will be leaving the pool of labor, departure, which grossly stated, also depends on the total number of individuals composing the labor force. Hence, the 'net' natural growth in labor force, as frequently stated, is proportional to the current labor force (equation 4 and 5). The constant of proportionality (0.028) is less than the natural fraction of population growth given by demographic sources (0.035) but high enough to reflect the frequent use of very young persons in coffee and other agricultural activities.

Migration to urban centers results from the tendency of developing economies to industrialize and to switch human resources devoted to agricultural pursuits in favor of industrial and service activities. The gradual change from an agricultural to industrial base is accomplished through the acquisition of productive capital whose equipments and techniques upgrade the output and distribution of food among the growing population, and create accumulation of wealth to expand the industrial base. On the other hand, the use of productive capital in the rural sector compels idle labor to move to city centers and to engage in better paid industrial jobs, with the hope of reaching the higher standard of living generally provided by urban life. Hence, migration rates depend on the total pool of rural workers (ALABF) and also, on the attractiveness posed to the peasant by living



conditions in the city (Equation 6).

$$R \quad NGALF.KL = ALABF.K * PYGAL * GROWTH.K \quad (4)$$

$$C \quad PYGAL = 0.028$$

$$R \quad NGULF.KL = ULABF.K * PYGUL * GROWTH.K \quad (5)$$

$$C \quad PYGUL = 0.02$$

$$R \quad MTUC.KL = ALABF.K * NPYM * ATUC.K * GROWTH.K \quad (6)$$

$$C \quad NPYM = 0.01$$

- \*NGALF - Natural Growth Rate Agricultural Labor Force (men/year)
- PYGAL - Yearly Growth Fraction, Agricultural Labor Force (Fraction/Year)
- GROWTH - 0, 1 Variable to Test Model without/with Growth (Dimensionless)
- \*NGULF - Natural Growth Rate Urban Labor Force (men/year)
- PYGUL - Yearly Growth Fraction Urban Labor Force (Fraction/Year)
- \*MTUC - Migration Rate to Urban Centers (men/year)
- NPYM - Normal Fraction Yearly Migration (Fraction/Year)
- ATUC - Attraction to Urban Centers (Dimensionless)

### 3. Attraction to Crop Coffee (ATCC) and Available Supply of Labor (AVCL)

Only a fraction of the agricultural labor force (ALABF) of a producing nation lives within areas suitable to coffee cropping. Generally, a farmer will be attracted toward a coffee area when he expects to get a higher income and standard of living than the one he gets if engaged in other regions. For similar reasons, a farmer who owns a plot of land within a coffee area may choose to plant and harvest coffee trees. In the case of coffee, the returns to the peasant include his wages,

if a worker, or his wages and profits if he owns the land, plus several other benefits he normally receives from official institutions whose purpose is to maintain and support the pool of coffee growers. In fact, the income per capita in most states whose economic base is coffee tends to be higher than in other regions dedicated to other agricultural pursuits, despite their higher levels of population densities and growth rates.<sup>2)</sup> Hence, the supply of labor in the coffee areas depends on the ratio between the earned coffee income per capita and the income he will receive if engaged in other activities.

Equation (7) shows the total producers' income (PROIN), the product of whatever was produced during a year, and the domestic price per bag received by the farmer--all production can be sold at a floor price to the official coffee institutions. The current labor employed in coffee is given by EMCL, in equations (8). The first of these two equations gives the maximum employable labor force (IEMCL), this is the product among the total land used (LAND+LABP), the labor units required per hectare (LUPHA) and the fraction of acreage being actually harvested (1-ABFRT). The second equation indicates that the actual employed labor (EMCL) cannot be higher than the current availability of labor (AVCL). The value for the parameter labor-units-per-hectare (LUPHA = 0.200) has been adjusted from data presented by Kalmanoff [16, p. 59 to 62].

Equations (9) develop the relative income per labor unit (ARIPLU). As this ratio increases above one, the cropping of coffee becomes more and more

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<sup>2)</sup> The coffee states of Antioquia, Caldas and Quindio in Colombia; Parama and Sao Paulo in Brazil.

attractive to both the farm owner and worker; on the other hand, during periods of depressed prices and income, many workers and farmers may instead seek employment in other activities. This relationship appears in equation (10) and graphically in Figure B1-a, where the variable 'attractiveness to Crop Coffee' (ATCC) is measured on a scale from 0.4 to 1.6. A value of one, in ATCC, means that the earned coffee income per labor unit is about the same as incomes earned in other economic activities within the same coffee area or its surroundings, and hence, there is no incentive to enter or leave coffee farms. On the other hand, even if the relative income per labor unit (RIPLU) or more precisely, its expected value (the average of RIPLU) is just below one, but laborers expect their coffee income to increase at a faster rate, many of them will decide to stay within the coffee activity, rather than leave it, unless the workers and the public expect a drastic income reduction. This is the meaning attached to Figure B1-b. The reader may note the different shape exhibited by the two previous relationships. In Fig. B-1-a, Attractiveness to Crop Coffee, (ATCC) grows or decays exponentially with the average relative income--that is, with the current benefits received from being a coffee harvester. On the other hand, in Figure B1-b, the effect due to average income change reflects future expectations; certainly, the farmer of a traditional agricultural base, as coffee, will tend to judge future expectations about his income with caution. Hence, if our hypothesis is right, the shape of the curve should gradually approach a maximum (and a minimum) beyond which a rapid (expected) income change would not suffice to make the owner of the farms to plant more trees, or to attract more labor. This is the meaning of equation 12 .

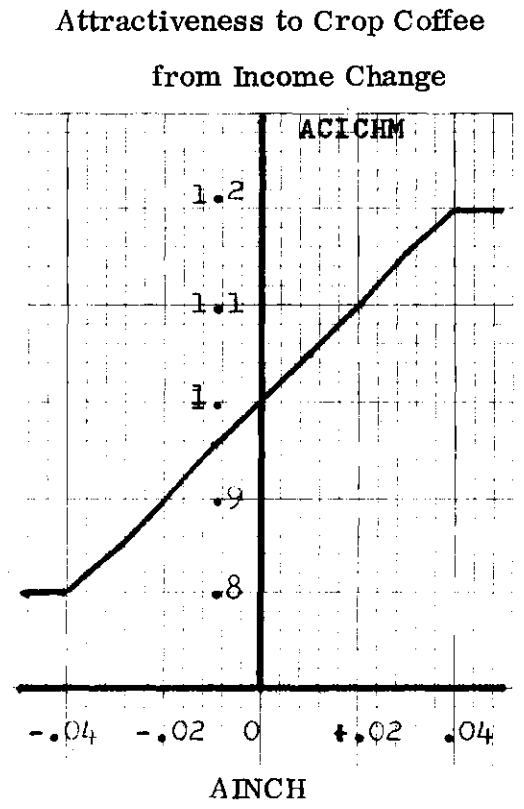
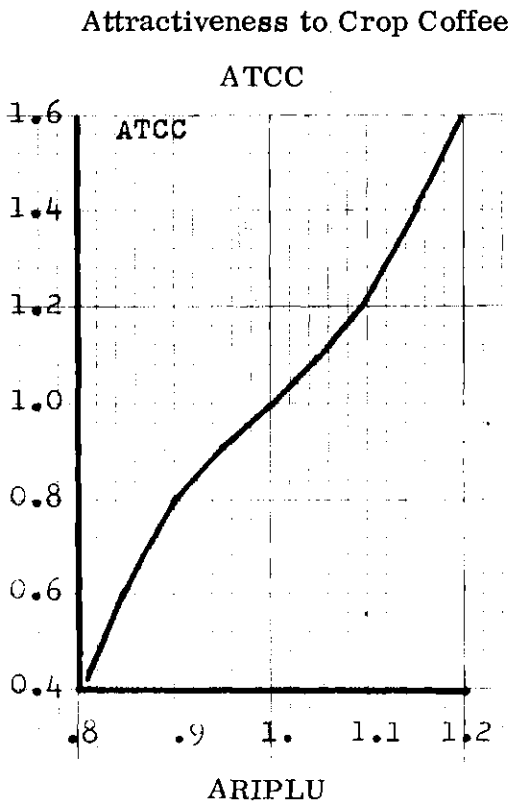


Figure B-1. Attractiveness to Crop Coffee.

- A  $PROIN.K = ADPR.K * APRR.K \times 10^6$  (7)
- A  $LEMCL.K = (LAND.K + LABP.K) * LUPHA * (1 - ABFRJ.K)$  } (8)
- A  $EMCL.K = MIN(LEMCL.K, AVCL.K)$
- C  $LUPHA = 0.200$
- A  $INPLU.K = PROIN.K / EMCL.K$
- A  $RINPLU.K = INPLU.K / MINPL$  (9)
- N  $MINPL = INPLU$
- A  $ARIPLU.K = SMOOTH(RINPLU.K, 1)$
- A  $ATCC.K = TABHL(TATC, ARIPLU.K, 0.8, 1.2, 0.05)$  (10)
- T  $TATC = 0.4/0.6/0.8/0.9/1/1.1/1.2/1.4/1.6$
- A  $AINCH.K = SMOOTH(RINPLU.K - ARINPLU.K / ARIPLU.K, 1)$  (11)
- A  $ACICHM.K = TABHL(TATH, AINCH.K, -0.05, 0.05, 0.01)$  (12)
- T  $TATH = 0.8/0.8/0.85/0.9/0.95/1/1.05/1.1/1.15/1.2/1.2$

PROIN	-	Producers' Income (\$/year)
ADPR	-	Average Domestic Price (\$/bag)
APRR	-	Average Production Rate (million bags/year)
EMCL	-	Employment Coffee Labor (men)
LAND } LABP }	-	Total Used Land (hectares)
LUPHA	-	Labor Unit per Hectare (men/ha)
ABFRT	-	Abandoned Fraction of Trees (fraction)
AVCL	-	Available Coffee Labor (Men)
INPLU	-	Income per Labor Unit (\$/men-year)
MINPLU	-	Minimum Income per Labor Units in Non-Coffee Activities (\$/men-year)
RINPLU	-	Relative Income per Labor Unit (Dimensionless)
ARIPLU	-	Average of RINPLU (Dimensionless)
ATCC	-	Attractiveness to Crop Coffee (Dimensionless)
AINCH	-	Average Income Change (Fraction)
ACICHM	-	Attractiveness to Crop Coffee from Income Change (a Multiplier) (Dimensionless)

Finally, the supply of labor, Available-Coffee-Labor (AVCL) is given by the fraction of agricultural labor force (ALABF) willing to engage in coffee cropping activities; equation 13. A normal fraction (NFRCL) of about 0.25 seems to be a good choice after reviewing information about Colombia and Brazil.<sup>3)</sup> The smooth operation in the same equations takes into account the fact that newly developed conditions in the coffee business, do not attract labor immediately. On the average, a delay of one year may be a reasonable value.

$$\begin{aligned} A \quad AVCLI.K &= ALABF.K * NFRCL * ATCC.K * ACICHH.K \\ C \quad NFRCL &= 0.25 \end{aligned} \tag{13}$$

$$A \quad AVCL.K = \text{SMOOTH}(AVCLI.K, 1)$$

AVCLI	-	Available Coffee Labor Indicated
		(men)
NFRCL	-	Normal Fraction Coffee Labor (fraction)
ATCC		Attractiveness to Crop Coffee
		(Dimensionless)
ACICHH		(Two Multipliers)
AVCL	-	Available Coffee Labor (men)

#### 4. Desired Land to Plant Coffee Trees (DELND)

The opening of new lands to cultivate coffee trees depends on the benefits the farmer expects to receive from enlarging his coffee acreage as compared with the gains he would receive by cultivating other crop(s). The advantages deriving from coffee cultivation result, primarily, from the nature of this crop which requires large quantities of human labor and does not need complex and costly

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<sup>3)</sup> See Kalmanoff [16 p.28] and bulletins by the Pan American Coffee Bureau [29, 30, and 31].

agricultural equipment, and secondly, on the application of several governmental policies conceived to protect and maintain the pool of coffee farmers and their productive stocks of trees, as described in the previous section. The main determinant of acreage dedicated to coffee is the availability and cost of labor. Figure B2 exhibits the estimated cost structure in typical farms in Colombia at different levels of yields per hectare. At lower yields, labor costs account for almost all the costs incurred; however, as the yields increase the participation of labor costs decay toward a 70% of the total costs; still a high figure.<sup>4)</sup> Therefore, a farmer who considers whether to plant coffee trees or use his land for other type of product would weight the probable cost of the labor he would use in coffee, versus the costly capital he would require in the alternative crop, unless, of course, the substitute crop requires as much labor and as few capital as coffee. Furthermore, the farmer who owns a small plot, who does not have readily access to credit and finance and who has cultural attachments to agricultural tradition will show a preference for coffee, a product with lower operating risks, among other things, because of the floor price the governments normally guarantee on surplus output, and also a crop in which the farmer can use most of his family to provide cheap non-waged labor. Certainly, not by coincidence, most coffee areas where the land tenure is composed by small plots typically show families with six or more children, as happens in the coffee states of

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<sup>4)</sup> The structure of costs in other countries follows a similar pattern. Wickizen in Coffee, Tea and Cocoa (p. 492) claims that on the average labor costs represent 75% of the total operating cost of the farms.

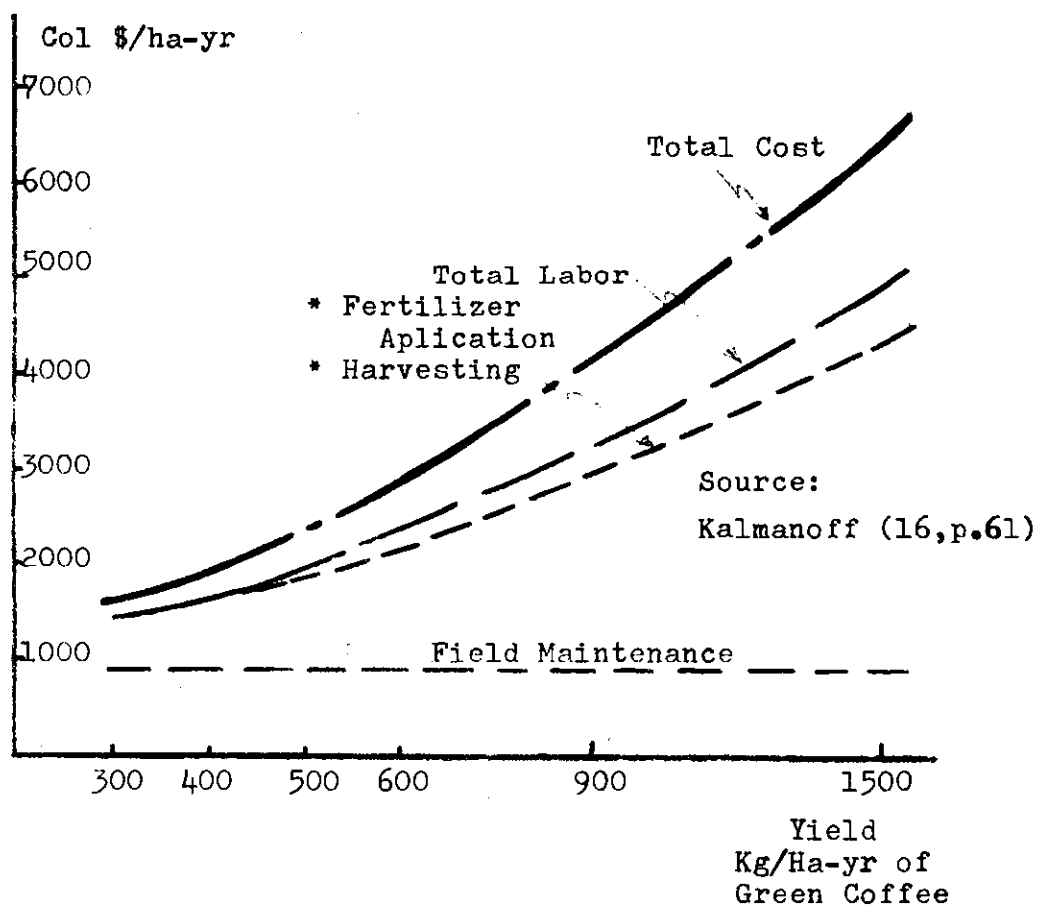


Figure B2. Estimated Cost Estructure at Different Yields per Hectare in Colombia (1967).



Colombia.

In Brazil, where the size of the farms tends to be larger, the availability of labor to weed, plant and harvest the coffee plantation has been a salient and recurrent problem. Furtado (11, chapter on Coffee) describes several periods during the economic history of Brazil in which the scarcity of labor created serious obstacles to the expansion of Brazil coffee acreage. In turn, Arak (1, p. 214) has presented the situation of the Sao Paulo coffee grower in the following terms:

...In Sao Paulo the main barrier to the immediate expansion of coffee cultivation to the 'desired' [acreage] level was labor. The coffee sector which absorbed a large portion of Sao Paulo's labor force was not a perfect competitor in the labor market. Future labor costs thus depended significantly upon demand for labor in the coffee sector, *ceteris paribus*. In deciding whether to plant a new tree in year  $t$  or in a later year  $t+1$ , the rational farmer would consider, among other things, the probable demand for labor in the two years. ...

Therefore, as shown by equation 14, the desired acreage in coffee depends primarily on the availability of coffee labor (AVCL). Furthermore, given an established price to the farmer's output, there would be a land extension which will return larger profits in coffee than in other crops. Thus, when prices are high and the farmer expects them to be even higher, it would pay him to incur larger labor wages to get enough labor to expand, prepare, weed and plant additional acres of land. Conversely, at lower and declining prices the farmer may not expand his coffee acreage, but rather may prefer to dedicate a portion of his coffee land to other activities, in which case he will have to pay the high cost involved in uprooting obsolete trees, or if no other alternative seems possible, he may decide to keep his current acreage and not harvest a fraction of his trees.

Thus, equations 14 and 15 describe the desired land in coffee as determined by the available labor (AVCL) and also by adjusting effects due to both, the current level of prices and the farmer's expectations about price change. These two effects, LPM and LPCHM have been depicted in Figure B3.

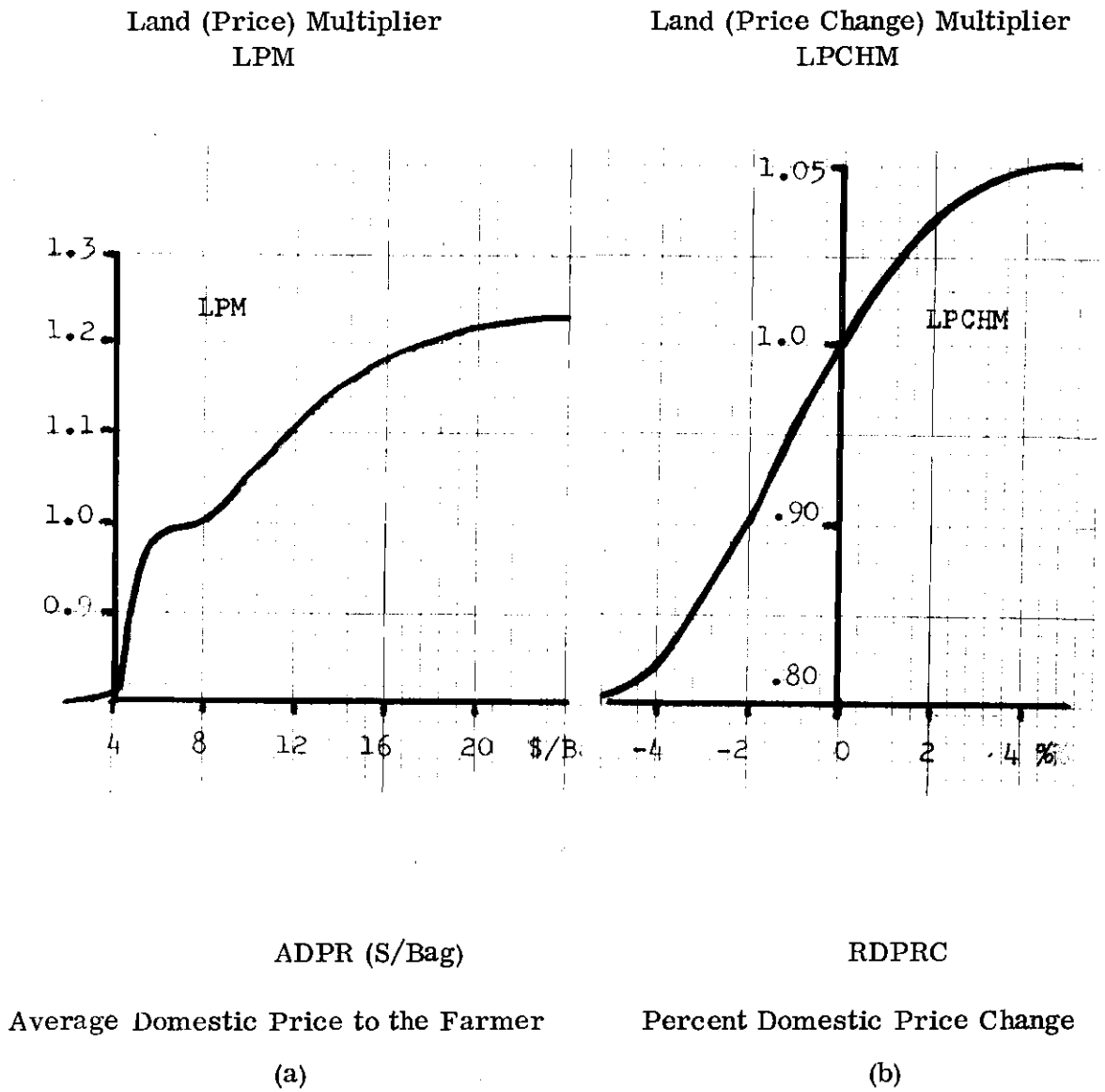


Figure B3. Land Multipliers.

A value of about \$6 /Bag of green coffee to the farmer appears enough to maintain his actual acreage; in this case no further land expansion is induced, (LPM=1). As price rises, new lands are opened to crop coffee, with the result that labor and possible land, will tend to become scarce and more costly. This is one of the reasons to explain the gradual leveling of the land (price) multiplier at high prices, (LPM  $\simeq$  1.23). The other reason is associated with the farmer expectations about the stability of high coffee prices. Most of them know that very high prices will not last long and if high enough, a reversing price trend may be approaching; hence, the farmer will tend to become more conservative in his decision to expand acreage at these high price levels. On the other hand, a reduction in prices below \$6/Bag, tends to create income to the farmer near or below his subsistence level, and only a few of them will be willing to expand acreage (LPM=0.8). See equation 16.

The rationale to explain the shape of the land (price change) multiplier (LPCHM) in equation 17 is very similar to the one presented above. Price change is an indication of the future price level, hence a measurement of price expectations. Furthermore, the two multipliers, LPM and LPCHM combine themselves to evaluate current and expected developments in the coffee market. The multiplication of these two variables, and not their addition for example, is the reflection that a farmer should react very differently to high and rising prices than to high but declining prices, or any other possible combination of terms (equation 15).

Finally, desired land (DELND) has been taken as a smoothed (average)

version of the desired land indicated (DELNI). The effect of the smooth operator (equation 18) is to create a weighted average of past developments, in which the weight is higher for more recent events than for more distant. This final equation describes the gradual process of adjustment that should occur when say, unexpected exogenous disturbances affect price developments. If the current state of affairs indicates a total desired acreage of 1000 hectares and a sudden disturbance points at 5000 hectares, farmers may not be willing and may not have the required resources on hand to rapidly change their desires and expectations that rapidly. Rather, if the sudden disturbance persists, they will gradually reach the conviction that new additional land really creates a lasting and profitable opportunity.

In this research most smooth operators have the same meaning attached above, unless specifically stated otherwise. Further description of this type of equations will be committed hereafter.

$$A \quad \text{NDLAND.K} = \text{AVCL.K} / \text{LUPHA} \quad (14)$$

$$A \quad \text{DELNI.K} = \text{NDLAND.K} * \text{LPM.K} * \text{LPCHM.K} \quad (15)$$

$$A \quad \text{LPM.K} = \text{TABHL}(\text{TLPM}, \text{ADPR.K}, 4, 24, 2) \quad (16)$$

$$T \quad \text{TLPM} = 0.8/1/1/1.05/1.1/1.15/1.18/1.2/1.22/1.23/1.23$$

$$A \quad \text{LPCHM.K} = \text{TABHL}(\text{TLPC}, \text{RDPRC.K}, -0.05, 0.05, 0.01) \quad (17)$$

$$T \quad \text{TLPC} = 0.9/0.91/0.93/0.95/0.98/1/1.03/1.035/1.04/1.05/1.05$$

$$A \quad \text{DELND.K} = \text{SMOOTH}(\text{DELNI.K}, \text{TADL}) \quad (18)$$

$$C \quad \text{TADL} = 1$$

NDLAND	- Normal Desired Land (Hectares)
DELNI	- Desired Land Indicated (Hectares)
LPM	- Land (Price) Multiplier (Dimensionless)
LPCHM	- Land (Price Change) Multiplier (Dimensionless)
DELND	- Desired Land in Coffee (Hectares)
TADL	- Delay to Adjust Desired Value (Years)

### 5. Land Preparation Rate (LPR) and Land

#### Removal Rate (LRR)

The amount of hectares per year to be cleared, weeded and conditioned to support coffee trees is the land preparation rate (LPR). As said before, the desired land in coffee (DELND) is the total acreage the farmer is willing to use in coffee. Therefore, the yearly additions of land (LPR) can be easily calculated as a fraction of the difference between the desired acreage and the current land in coffee. If the farmer is able to adjust his land to the desired value in just one year, he would add hectares of coffee land equal to the difference between the desired and the actual hectares used; on the other hand, if the land he intends to use is currently utilized with other crops, he will probably have to wait until the next harvesting period to collect his cash and invest in coffee. Let us say then, that each year, the farmer can adjust only 50% of the difference between the target area and the current used land (equations 19).

The total number of hectares of land being cleared, weeded and prepared to transplant small coffee trees is defined here as Land Being Prepared (LABP) equation 20. One or two years thereafter when the land has received proper treatment and rest, new land will be ready to support coffee trees. Thus, every



$$L \quad LAND.K = LAND.J + DT * (NLAR.JK - LRR.JK) \quad (22)$$

$$R \quad LRR.KL = ATRR.K * HAPTR \quad (23)$$

$$C \quad HAPTR = 0.001$$

- \* LNDA - Land Adjustment (hectares/year)
- LCT - Land Correction Time (years)
- \* LPR - Land Preparation Rate  
(hectares/year)
- \* LABP - Land Being Prepared (hectares)
- \* NLAR - Net Land Arrival Rate  
(hectares/year)
- DTUL - Delay to Utilize Land (years)
- \* LAND - Land Used and Usable in Coffee  
(hectares)
- \* LRR - Land Removal Rate (hectares/year)
- ATTR - Average Tree Removal Rate  
(Trees/year)
- HAPTR - Hectares per Tree (ha/Tree)

#### 6. Available Land to Plant New Trees (AVLND)

The difference between the total land currently used and usable (LAND) and the actually planted acreage gives the available land to plant additional trees (AVLND). In turn, the extension of hectares planted with trees (used land = USLND) is simply the product of the total number of standing trees and the hectares required per each tree (equations, 24, 25).

$$A \quad USLND.K = TTR.K * HAPTR \quad (24)$$

$$A \quad AVLND.K = LAND.K - USLND.K \quad (25)$$

- \* USLND - Used Land in Standing Trees  
(hectares)
- \* AVLND - Available Land to Plant New Trees  
(hectares)

### 7. Planting Rate (PLR)

The seeding and cultivation of the small coffee plants of the mild type is normally accomplished in a shaded nursery bed, near to the place where the plant will definitely stand as a coffee tree. Thus, planting rate (PLR) refers here to the number of trees one or less years old which are transplanted to the field during each year. Depending upon the variety of coffee, trees are planted closer or farther from each other. On the average, a space of some  $10 \text{ m}^2$  per tree seems to be a good number, figure which is equivalent to 1000 trees per hectare. ( $\text{HAPTR} = 0.001 \text{ ha/tree}$ ). Furthermore, how quickly the available land (AVLND) is to be covered with trees depends on several things. First, the availability of labor to accomplish the task; second, if the farmer owns a large proportion of obsolete capacity he may choose to rapidly plant the new varieties to renovate his plantation, and finally, if the expected yield of the newly seeded trees is higher than the yield of his obsolete trees, he may as well decide to enlarge the proportion of new trees and plant more frequently (Arak 1, p. 213).

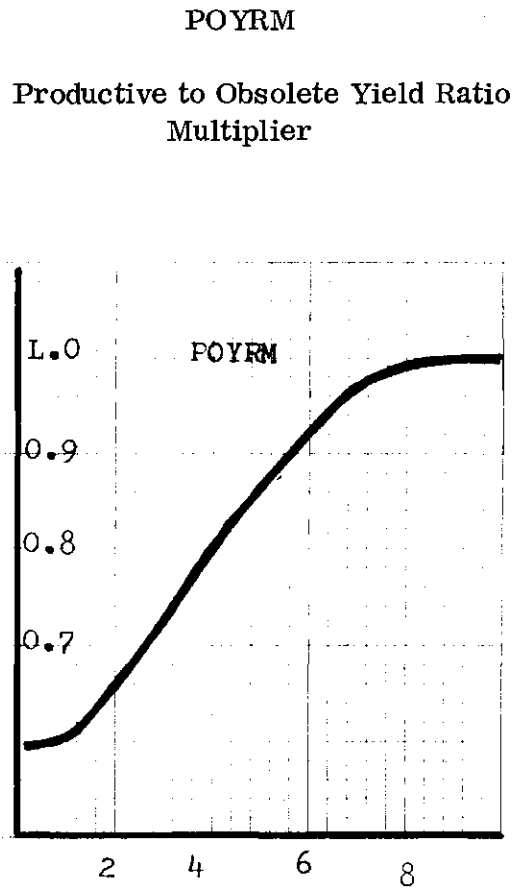
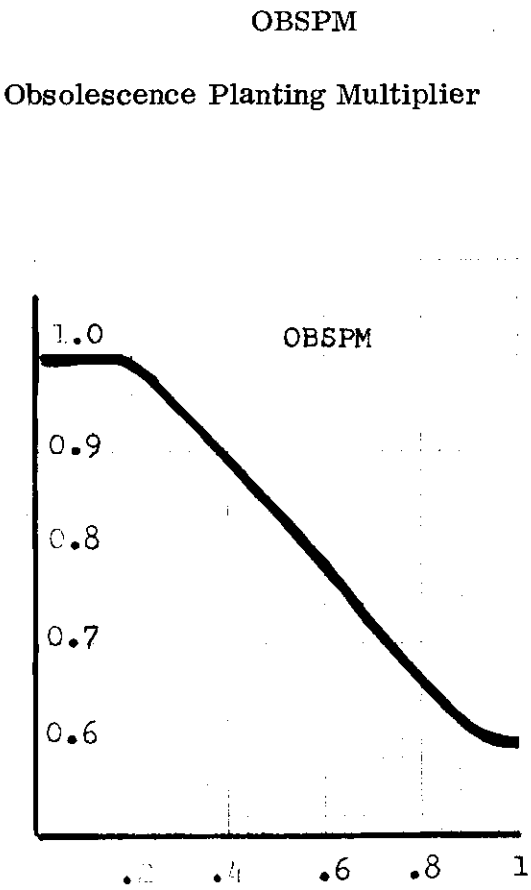
Equations 26 and 27 describe this mechanism. The available land (AVLND) divided by the number of hectares per tree (HAPTR) gives the maximum number of trees to plant. Depending upon the conditions stated above, only a fraction of this amount will be planted each year, i.e.  $1/\text{PLCT.K}$ . Furthermore, one can confidently assume that under most normal circumstances, the farmer will never choose to uproot some of the newly planted trees; PLR is positive. Instead, as Arak and many others have pointed out, if general conditions in the coffee market are poor, the farmer may rather choose not to plant at all and perhaps may uproot



some of his oldest trees [1, p. 214].

The speed at which the farmer wants to plant is captured in the concept Planting-Correction-Time (PLCT). As indicated previously, this is the number of years required to plant the whole available land, or stated in another way, the inverse of this number shows how fast the available land is used. Equation 27 shows the Planting-Correction-Time (PLCT) as affected by both the fraction of obsolete trees through a multiplier, the obsolescence-Plant-Multiplier (OBSPM) and the ratio between the highly productive yields of young trees and the low yield of older trees. This latter effect is described as Productive-to-Obsolete-Yield-Ratio-Multiplier (POYRM). The effect of labor availability on planting speed has been excluded, although labor indirectly affects the planting rate, in view of our assumptions about land expansion.

Figure B4-a exhibits the values and shape of the two planting multipliers. When there is almost no obsolete capacity ( $FOTR=0$ ), planting correction time is not reduced, and the speed of planting will proceed normally. Initially, gradual increases in the amount of obsolete trees may pass unnoticed to the farmer to promote rapid planting; later on, however, when it becomes clear to him that more than 60% of his tree stock is old, he will decide to increase the renovation rate of his plantation. This is the reason underlying the gradual decay in the obsolescence planting multiplier (OBSPM). On the other hand, even if the farmer wishes to plant his available area very rapidly, he will encounter a limit beyond which it will be impossible to accelerate the pace of planting. Hence, the curve gradually bends toward this lower limit. See Figure B4-a, and equation 28.



FOTR  
Fraction Obsolete Trees  
(a)

POYR  
Productive to Obsolete Yield Ratio  
(b)

Figure B4. Planting Multipliers.

Similarly, when the total stock of trees is relatively old, the yield ratio between the more productive and less productive trees is close to one, and also each one of the yields will be lower. Thus it becomes more urgent to plant young trees to re-establish yields with larger profits. On the other hand, as the stock of trees becomes gradually younger, the rising yield ratio will tend to restrain the speed at which the plantation is renovated--renovation becomes less urgent, a fact which explains the diminishing change exhibited by the Yield-Ratio-Planting-Multiplier (POYRM) as it approaches high values (Fig. B4-b and equation 29.)

Finally, the fraction of obsolete trees (FOTR) is stated as the ratio of the total obsolete capacity (OBTR) and the total number of trees (TTR) in the plantation (equation 30).

$$R \quad PLR.KL = \text{MAX}(AVLND.K / (HAPTR * PLCT.K), 0) \quad (26)$$

$$C \quad HAPTR = 0.001$$

$$A \quad PLCT.K = NPLCT * OBSPM.K * POYRM.K \quad (27)$$

$$C \quad NPLCT = 3$$

$$A \quad OBSPM.K = \text{TABHL}(TUPM, FOTR.K, 0, 1, 0.1) \quad (28)$$

$$T \quad TOPM = 1/1/1/0.95/0.9/0.85/0.80/0.75/0.7/0.60/0.60$$

$$A \quad POYRM.K = \text{TABHL}(TYRM, POYR.K, 1, 10, 1) \quad (29)$$

$$T \quad TYRM = 0.6/0.7/0.75/0.8/0.85/0.9/0.95/1/1/1$$

$$A \quad FOTR.K = OBTR.K / TTR.K \quad (30)$$

\* PLR        - Planting Rate (Trees/year)

\* PLCT      - Planting Correction Time (years)

	NPLCT	- Normal Planting Correction Time (Years)
*	OBSPM	- Obsolescence Planting Multiplier (Dimensionless)
*	FOTR	- Percent of Obsolete Trees (Fraction Dimensionless)
	OBTR	- Obsolete Stock of Trees (Trees)
	TTR	- Total Stock of Trees (Trees)
*	POYRM	- Productive-to-Obsolete Yield Ratio Multiplier (Dimensionless)

### 8. Maturing Delay (MATR)

On the average, a newly planted tree will reach reasonable productive levels four years later. The total stock of maturing trees (MATR) at year  $t$ , can be easily obtained from both the planting rate (PLR) and the trees which become mature during the year (MTRR) and the stock of maturing trees at year  $t - 1$  (equation 31). All the maturing trees will not, however, mature at the same time. Some will reach maturity sooner, others will have a longer gestation period; nevertheless, on the average, most of the trees will mature after four years of planting. To simulate this effect, the DYNAMO compiler provides a third order delay, as displayed in equation 32, where MTRR stands for the flow of trees which every year attain full productive levels.

During the last two centuries, the average delay to mature (the four year period) have suffered alterations. New seeds and types of trees have been developed and several technological improvements have been used to shorten the long years of gestation. For instance, in Colombia there are special types of trees whose maturity can be obtained after only a three year period. Therefore, one could safely assume that crop technology has a definite effect on this type of delay, as presented by equations 33 to 35 and Figure B5.

## TECHD

## Technology Effects on Maturing Delay

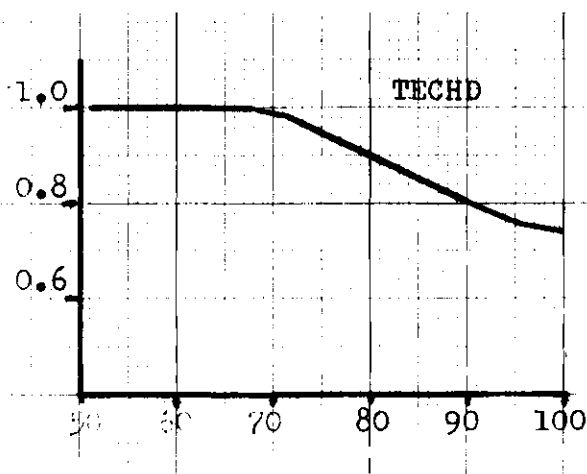


Figure B5. Index of Development of the Coffee  
Producing Nations.

$$L \quad \text{MATR.K} = \text{MATR.J} + \text{DT} * (\text{PLR.JK} - \text{MTRR.JK}) \quad (31)$$

$$R \quad \text{MTRR.KL} = \text{DELAY3}(\text{PLR.JK}, \text{CMATD.K}) \quad (32)$$

$$A \quad \text{CMATD.K} = \text{MATD} * \text{TECHED.K} \quad (33)$$

$$C \quad \text{MATD} = 4$$

$$A \quad \text{TECHED.K} = \text{SMOOTH}(\text{TECHD.K}, 5) \quad (34)$$

$$A \quad \text{TECHD.K} = \text{TABHL}(\text{TECD}, \text{DEVIN.K}, 50, 100, 10) \quad (35)$$

$$T \quad \text{TECD} = 1/1/1/0.90/0.80/0.75$$

- \* MATR - Stock of Maturing Trees (Trees)
- \* MTRR - Maturing Tree Rate (Trees/year)
- \* CMATD - Current Maturing Delay (years)
- MATD - Normal Maturing Delay (years)
- \* TECHD - Technology Effect on Maturing Delay (Dimensionless)
- 5 - Years Required to Start Using New Technological Developments
- \* TECHD - Technological Developments on Maturing Delay (Dimensionless)
- DEVIN - Development Index of the World Coffee Producing Nations (Dimensionless)

#### 9. Productive and Obsolete Stocks of Trees (HPTR, OBTR)

The yield of coffee trees depends primarily on the age of the tree. Typically, the yield of the tree will rise during the first sixteen or eighteen years, after which it will gradually decay. Highly productive trees are those trees whose yield has not decayed yet, while obsolete trees are defined here as trees with lower and decreasing yields. Further, a tree which has matured enters to form part of the stock of highly productive trees (HPTR), stays there for several years, twelve on the average, and then as its yield decays becomes obsolete. The number of trees which becomes obsolete during a year is the Tree Obsolescence Rate (TOBR). Hence, the stock of Highly Productive Trees (HPTR) at the end of a year, is equal to the stock of trees in the same group one year before, plus the trees which matured during the year (MTRR) minus the Tree-Obsolescence-Rate (TOBR). Similarly, the stock of obsolete trees (OBTR) at the end of a year, is equal to last

year's stock of obsolete trees plus the flow of obsoleted trees during the year (TOBR) minus the number of trees uprooted during the year, the Tree Removal Rate (TRR) (equations 36 and 37). The total number of trees (TTR) is then the addition of the Maturing Stock of Trees (MATR), the Highly Productive Stock of Trees (HPTR) and the Obsolete group of Trees (OBTR).

$$L \quad HPTR.K = HPTR.J + DT * (MTRR.JK - TOBR.JK) \quad (36)$$

$$L \quad OBTR.K = OBTR.J + DT * (TOBR.JK - TRR.JK) \quad (37)$$

$$A \quad TTR.K = OBTR.K + HPTR.K + MATR.K \quad (38)$$

- \* HPTR      - Highly Productive Trees (Trees)
- MTRR    - Maturing Trees Rate (Trees/year)
- TOBR    - Tree Obsolescence Rate (Trees/year)
- \* OBTR      - Obsolete Trees (Trees)
- TRR     - Tree Removal Rate (Trees/year)
- \* TTR       - Total Tree Stock (Trees)

#### 10. Average Age of Trees (AAMT, AAPT, AAOT)

The ratio between the total amount of maturing trees (MATR) and the average flow of trees reaching maturity (HTRR) gives an estimation of the number of years a newly planted tree requires to exit the maturing group and becomes a mature tree. For instance, let us say that there are a billion trees currently maturing. If the number of trees reaching maturity each year is on the average of 250 million per year, then the average age of each one of these trees is about 4 years. Similarly, the average number of years a tree remains as a highly productive tree is equal to the ratio between the stock of trees in this group (HPTR) and the average rate at which trees leave that group, i.e. the obsolescence rate

(TOBR). Thus, the average age of a tree being obsoleted is then the addition of the years during which it was productive enough and the age it had when it first reached maturity. In the equations below, AAMT is the current average age of the maturing trees, and AAPT stands for the current average age of the productive trees. The second term of AAPT simply is the average number of years a tree remains as productive, while the first term, SMOOTH(AAMT.K, MATD) is an estimation of the age of the productive tree when first reached maturity (equation 43). Similar expressions hold for the average age of the obsolete trees, (AAOT). The reader should go through the following equations, with the understanding that they represent gross approximations to the real average age of the trees in each one of the three groups. What matters here, on the other hand, is not to be too precise about the age of the trees, but rather to be accurate on how the average age of each tree group compares with each other. Certainly, the same type of approximations have been made in regard to each tree-group, which implies that the age differential among them may be accurate enough for our purposes.

$$A \quad AMTRR.K = SMOOTH(MTRR.JK, 1) \quad (39)$$

$$A \quad ATOBR.K = SMOOTH(TOBR.JK, 1) \quad (40)$$

$$A \quad ATRR.K = SMOOTH(MTRR.JK, 1) \quad (41)$$

$$A \quad AAMT.K = MATR.K / AMTRR.K \quad (42)$$

$$N \quad AAMT = MATD (=4 \text{ Years})$$

$$A \quad AAPT.K = SMOOTH(AAMT.K, MATD) + HPTR.K / ATOBR.K \quad (43)$$



$$N \quad AAPT = MATD + 1 / NOBF (=16 \text{ Years})$$

$$A \quad AAOT.K = SMOOTH(AAPT.K, PROTD.K) + OBTR.K / ATRR.K \quad (44)$$

$$A \quad PROTD.K = HPTR.K / ATOBR.K \quad (45)$$

$$N \quad AAOT = AAPT + 1 / NORRF (= 32 \text{ years}).$$

AMTRR	- Average Maturing Rate (Trees/year)
ATOBR	- Average Trees Obsolescence Rate (Trees/years)
ATRR	- Average Tree Removal Rate (Trees/years)
* AAMT	- Average Age Maturing Trees (Years)
MATD	- Maturing Delay (Years)
* AAPT	- Average Age Productive Trees (Years)
* AADT	- Average Age Obsolete Trees (Years)

Note the input given to the initial values for the three ages. The constants NOBF and NORRF will be explained later, in the sections describing the Obsolescence and Removal Rates.

### 11. Average Yields (AYMT, AYPT, AYOT)

The yield obtained from coffee trees depends among several other things on the age of the tree, the number of years the land has supported coffee plants, the characteristics of the soil, the quality and quantity of the fertilizer used, and the cultivation and procedures used by the farmer, and the variety of tree used. Furthermore, the yield of the tree is subject to frequent year to year variations, most of which are motivated by the biological cycle of the coffee tree and also, by changes in the environment and weather. Despite all of these factors, the yield of the coffee tree, on the average, can be best represented as primarily determined by the age of the tree. Generally, the yield rapidly grows until about the time the tree is eight years old, then reaches a plateau which may last another

eight years, after which the yield gradually decays. By the time the tree is forty years old, its yield may be one third of the maximum yield. The yield pattern exhibited in Figure B6 and equations 46 to 48 is the type of yield rendered by most arabic species. The ordinate of the curve shows the number of bags of green coffee annually produced by the tree. Each bag weighs 60 Kg. ( $\approx$  132 U.S. pounds).

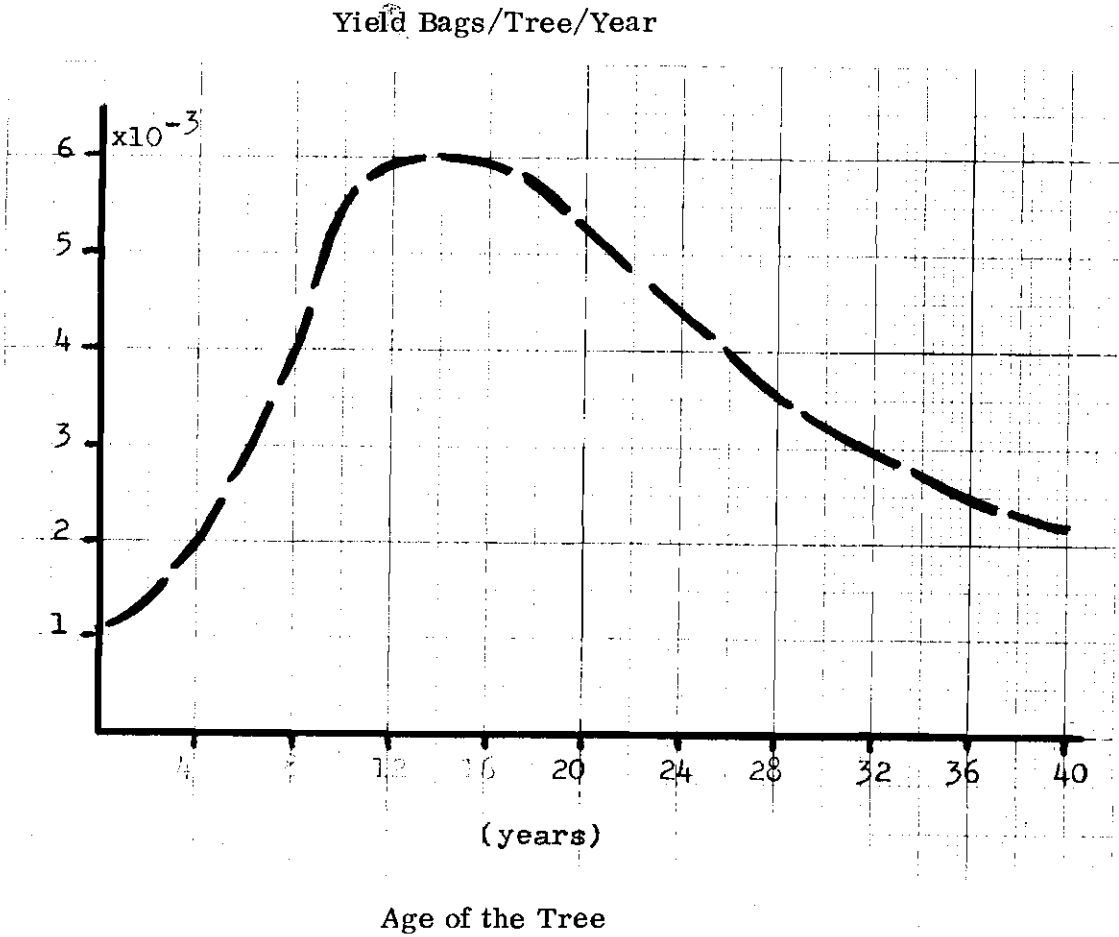


Figure B6. Yield of the Coffee Tree.

$$A \quad AYMT.K = TABHL(TPTY, AAMT.K, 0, 40, 4) * 10^{-3} \quad (46)$$

$$A \quad AYPT.K = TABHL(TPTY, AAPT.K, 0, 40, 4) * 10^{-3} \quad (47)$$

$$A \quad AYOT.K = TABHL(TPTY, AAOT.K, 0, 40, 4) * 10^{-3} \quad (48)$$

$$T \quad TPTY = 1/2/4/6/6/5.4/4.5/4/3.5/3/2.5/2$$

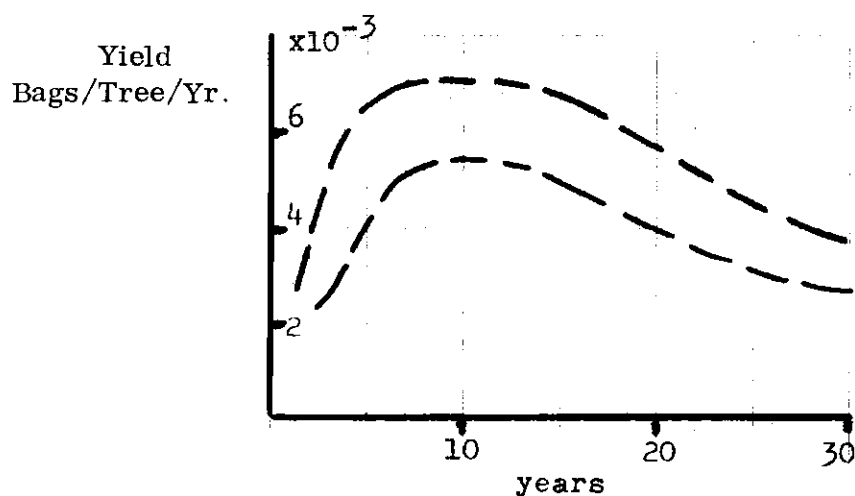
- \* AYMT - Average Yield Maturing Trees  
(Bags/Tree/Year)
- \* AYPT - Average Yield Productive Trees  
(Bags/Tree/Year)
- \* AYOT - Average Yield Obsolete Trees  
(Bags/Tree/Year)

## 12. Effective Yields (EYMT, EYPT, EYOT)

A farmer can upgrade his yields per tree with proper use of fertilizer and careful cultivation procedures. On the other hand, those who neglect or abandon their coffee crop are bound to receive low yields regardless of the youth of the plantation. Rowe[ 23 p. 37] describes widely different yields in two closely located farms in the state of Parama. In one farm, the agricultor followed cultivation practices recommended by the IBC, but did not add to the land fertilizer, as the land seemed to be in proper condition. In the other, the farmer was unable to pay enough labor to crop the trees, which forced him to provide a limited care to his trees, plus the fact that he had never used adequate shading procedures. Figure B7 depicts graphically Rowe's description. Given proper cultivation and care to the tree, yields may be almost twice as large as those with poor cultivation practices.

# Yields in Two Farms of the State of Parama

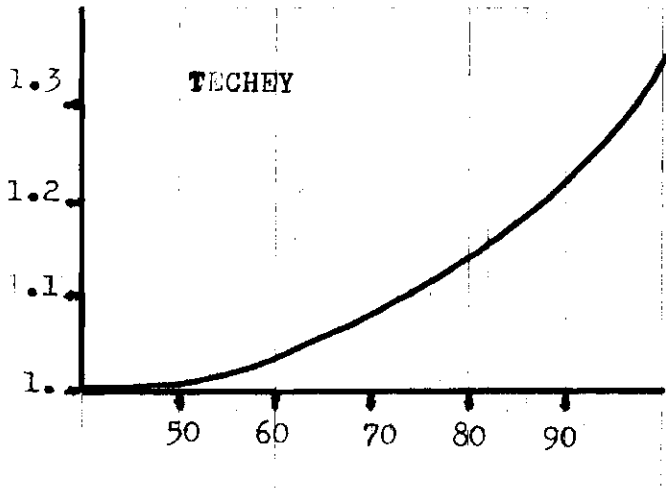
(as described by Rowe)



Age of Trees

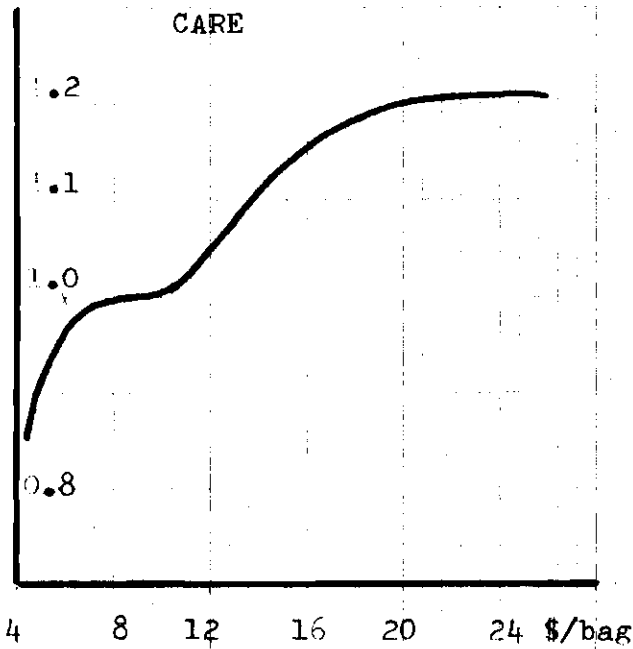
Figure B7. Effect of Cultivation Procedures on Yields.

The above illustration points out the salient effects of coffee cropping technology and the intensity of tree care to enhance coffee yields. Coffee growing technology includes such things as production of new seeds; the adequate control of shade and size of the tree; and the use of fertilizer, among others. As shown by equation 49 and Figure B8, most of these agricultural innovations have generally advanced pari-passu with the economic progress of the coffee nations, although



Development Index of  
Coffee Producer Nations

Figure B8. Technological Effects on Yield.



Average Domestic Price to the Farmer

Figure B9. Effect of Intensive Care on Yield.

the coffee farmer only gets the benefit several years later, the period of time required to perform field tests and to establish elaborate educational programs. This is the reason to 'smooth' the Technological Effects on the Yield (TECHEY) in equations 50 to 52. Furthermore, most technological advances together with the farmer's attitudes in favor of high yield trees give priority to new and younger trees. Obsolete trees very rarely benefit from this type of developments. Thus, equations 50 to 52 also assume that most types of technological improvements affect first the newly maturing plants and last the stock of obsolete trees. This is the reason to use the average age of the three tree groups (AAMT, AAPT, AAOT) as smoothing delays in these equations, respectively.

Equation 53 and Figure B9 describe the intensity of care (CARE) with which a farmer attends his plantation, as a function of the average (domestic) price (ADPR) he receives for the crop. As price rises the farmer owner tends to upgrade the quality of his labor intensive procedures and management of his piece of land. Human labor and managerial capabilities as well, have a limit beyond which further price increases will not suffice to bring about additional efficiency in the farm operation. Hence, the curve describing CARE gradually bends to level off at high domestic prices.

Equations 54 to 56 describe the effective yields for each one of the three tree groups. The equations show the average yields multiplied by the technological multipliers and by the intensity of care provided by the farmer.<sup>5)</sup>

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<sup>5)</sup> The listing of equations at the back of the appendix shows several other factors affecting the effective yields: BIOP stands for biological cycle effects; FROST

$$A \quad \text{TECHEY.K} = \text{TABHL}(\text{TECH}, \text{DEVIN.K}, 50, 100, 5) \quad (49)$$

$$T \quad \text{TECH} = 1/1.02/1.04/1.06/1.08/1.11/1.14/1.18/1.23/1.28/1.34$$

$$A \quad \text{TECHM.K} = \text{SMOOTH}(\text{TECHEY.K}, \text{AAMT.K}) \quad (50)$$

$$A \quad \text{TECHP.K} = \text{SMOOTH}(\text{TECHEY.K}, \text{AAPT.K}) \quad (51)$$

$$A \quad \text{TECHO.K} = \text{SMOOTH}(\text{TECHEY.K}, \text{AAOT.K}) \quad (52)$$

$$A \quad \text{CARE.K} = \text{TABHL}(\text{TCAR}, \text{ADPR.K}, 4, 24, 2) \quad (53)$$

$$T \quad \text{TCAR} = 0.8/1/1/1/1.05/1.1/1.15/1.18/1.2/1.21/1.21$$

$$A \quad \text{EYMT.K} = \text{AYMT.K} * \text{TECHM.K} * \text{CARE.K} \quad (54)$$

$$A \quad \text{EYPT.K} = \text{AYPT.K} * \text{TECHP.K} * \text{CARE.K} \quad (55)$$

$$A \quad \text{EYOT.K} = \text{AYOT.K} * \text{TECHO.K} * \text{CARE.K} \quad (56)$$

- \* TECHEY - Technological Effects on Yield  
(Dimensionless)
- \* TECHM Technological Improvements on
- \* TECHP } - Yield, Maturing, Productive and
- \* } - Obsolete Trees Respectively
- \* TECHO (Dimensionless)
- \* CARE - Intensity of Tree Care (Dimensionless)
- ADPR - Average Domestic Price (\$/Bag)
- \* EYMT } Effective Yields, Maturing
- \* EYPT } - Productive and Obsolete
- \* EYOT } - Trees ( $10^{-3}$  Bags/Tree/Yr.)
- AYMT } Average Yield, Maturing
- AYPT } - Productive and Obsolete
- AYOT } - Trees ( $10^{-3}$  Bags/Tree/Yr.)

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<sup>5)</sup> is an input test to check effects of adverse weather conditions; LFMP is low frequency random noise and YTEST is a parameter to test the model sensitivity to changes in average yield per tree. These are omitted here to make the text simpler.

### 13. Tree Obsolescence Rate (TOBR)

An old tree with low and declining yields is an obsolete tree. If all the trees in a farm were able to produce the same yield regardless of age, soil and fertilizer used, then the farmer would probably never complain about his older and obsolete capacity. Unfortunately, trees get older, and the older they get the less productive and costly they become; at the same time young trees and new species with higher yields constantly open to the farm owner attractive ways to get higher returns on investment and growth potential. Therefore, as more efficient young plantations develop, the farmer is apt to judge his more mature and older trees as a burden to his economic operation. Thus, in the face of newly and highly productive plants, older but still efficient trees will tend to be obsoleted faster.

The number of trees which are obsoleted per year is the Tree Obsolescence Rate (TOBR). With no technological advances, addition of fertilizer or intensive cultivation, the yield of a mature tree generally declines by the time the tree is sixteen years old. During the first four years, the plant was maturing; thus, on the average, a tree will remain as a highly productive tree (HPTR) for twelve years more, the period after which the tree will be considered by the farmer as an obsolete tree. If, on the other hand, there were say, 6 billion productive trees with varying ages, then about 0.5 billion trees ( $6 \div 12$  or  $6 \times 0.0833$ ) on the average, would be obsoleted each year.

The obsolescence multiplier (OBM) adjusts the speed at which matured trees are obsoleted. With newly matured stock, higher yield trees are added to the



total amount of the more productive trees (HPTR), therefore the average yield of trees in this group (EYPT) tends to become much larger than the average yield of the older obsoleted capacity (EYOT). Hence, trees which not long ago seemed to the farmer productive enough to warrant careful cultivation, will now appear as non-efficient and costly trees to support. These trees will tend to be neglected and soon will pass to enlarge the normal flow of capacity being obsoleted.

The above concepts are described below in equations 57 to 59. The Obsolescence Multiplier (OBM) is presented as an increasing function of the yield ratio between average yields of the productive and obsolete capacity groups (POYR). The Tree Obsolescence Rate (TOBR) depends on both the normal fraction of productive trees which each year surpass the 16th birthday ( $\text{NOBF} = 8.33\% = 1 \div 12 \text{ years}$ ) and the Obsolescence Multiplier (OBM), given by equation 58.

$$A \quad \text{POYR.K} = \text{EYPT.K} / \text{EYOT.K} \quad (57)$$

$$A \quad \text{OBMI.K} = (1 - \text{OBSLP}) + \text{OBSLP} * \text{POYR.K} / \text{NYR} \quad \left. \vphantom{\text{OBMI.K}} \right\} \quad (58)$$

$$A \quad \text{OBM.K} = \text{MAX}(\text{OBMI.K}, \text{MINOBM})$$

$$C \quad \text{NYR} = 2$$

$$C \quad \text{OBSLP} = 1.1$$

$$C \quad \text{MINOBM} = 0.1$$

$$C \quad \text{NYR} = 2$$

$$R \quad \text{TOBR.KL} = \text{HPTR.K} * \text{OBM.K} * \text{NOBF} \quad (59)$$

$$C \quad \text{NOBF} = 0.0833$$

POYR	-	Productive to Obsolete Yield Ratio (Dimensionless)
OBMI	-	Obsolescence Multiplier Indicated (Dimensionless)
OBM	-	Obsolescence Multiplier (Dimensionless)
OBSLP	-	Obsolescence Multiplier (Dimensionless)
NYR	-	Normal Yield Ratio (Dimensionless)
* TOBR	-	Tree Obsolescence Rate (Trees/year)
HPTR	-	Highly Productive Trees (Trees)
NOBF	-	Normal Obsolescence Fraction (Percent per Year)

#### 14. Tree Removal Rate (TRR)

Each year, a flow of newly obsoleted trees (TOBR) enlarge the stock of obsolete capacity (OBTR). At the same time, a fraction of the older and more obsolete trees are removed from the coffee plantation. A tree is removed because it is too old to bear profitable yield at low prices and the farmer wants to use the area for other purposes or simply because the tree has died, either naturally or because of adverse weather conditions.

Generally, a tree entering the obsolete capacity group is older than sixteen years. Thereafter, the tree's yield gradually decays until it dies at about forty years of age. Therefore, the tree will remain standing as obsolete capacity for a long period of around 24 years. On the other hand, and due to several economic and climactic factors, the farmer may decide to uproot his tree several years earlier. On the average, obsolete trees may stand during some 16 years as suggested by several sources in the literature review. Thus, the tree Removal Rate (TRR) given normal conditions, is a fraction of the Obsolete Capacity as given by equation 60 ( $OBTR \times NORRF$ ,  $NORRF=1/16$ ).

As the reader may suspect, the cost of removal of trees is a costly operation. The wealthy farmer may use mechanized equipment to uproot the trees, or if he owns cattle he may allow it to knock down the trees, and enable the area to become pasture more quickly. The small farmer, on the other hand, does not have as many alternatives open to him. He can not afford to pay high removal costs, unless he decided to use his family members for this purpose, and be willing to neglect the cultivation of the complementary crop he normally produces to maintain his sustenance income. Furthermore, year to year price fluctuation creates obstacles to uproot excess and obsolete capacity, which the farmer held on the assumption that it provides a 'safety stock of trees' from which profits could be obtained, in case a sudden increase in price occurs, as frequently happens in the coffee market. Then, although the level of coffee prices may have an effect on the normal fraction of trees to remove per year (NORRF), the direction of this effect is not clear, Arak [1, p.215]. Large and wealthy farmers will tend to react differently from the way the smaller peasants would under similar price developments. For this reason the Tree Removal Multiplier (TRRM) below equation 60 has a constant value equal to one.<sup>6)</sup>

$$R \quad TRR.KL=OBTR.K*NORRF*TRRM.K \quad (60)$$

$$C \quad NORRF=0.0625$$

$$A \quad TRRM.K=1$$

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<sup>6)</sup> The purpose to include this multiplier within the model was to perform sensitivity tests to check the model response to an environment mostly dominated by large farmers, in which case, TRRM decreases as prices rise.

- \* TRR        - Tree Removal Rate (Trees/Year)
- NORRF     - Normal Removal Fraction (%/Year)
- TRRM       - Tree Removal Multiplier  
(Dimensionless)

#### 15. Abandoned Fraction of Trees (ABFRT)

Abandoned Trees are trees which are not cultivated, their surrounding area not cleared of weeds and their yield of matured berries not picked. At lower prices the farmers may find it beneficial to abandon a fraction of their obsolete capacity whose declining yield does not suffice to cover labor cultivation costs and fertilizer expenditures. Conceptually, at each level of prices, there exist an 'optimal' age, beyond which it is not profitable to cultivate and harvest older trees. Thus, the rational farmer will tend to cultivate only trees whose dollar-yield is larger than the tree's maintenance and cultivation costs. This is illustrated in Figure B10. Each broken line shows the dollar-yield (yield  $\times$  price) of trees at different ages, given an established price. At higher prices the dollar-yield will appear shifted toward the top of the diagram, thus, the dollar-yield is a function of both the age of the tree and the domestic price to the former, i. e. dollar-yield =  $P_y(a)$ .

The solid line represents the average annual cost per tree at each different age. Younger trees normally require extensive labor care, while older trees with declining yields require similar labor but higher fertilizer expenditures; hence, under normal conditions, cost is primarily a function of age,  $\Phi(a)$ . At a price  $P_0$ , farmers will abandon trees older than  $\tilde{a}_0$  years of age, trees whose

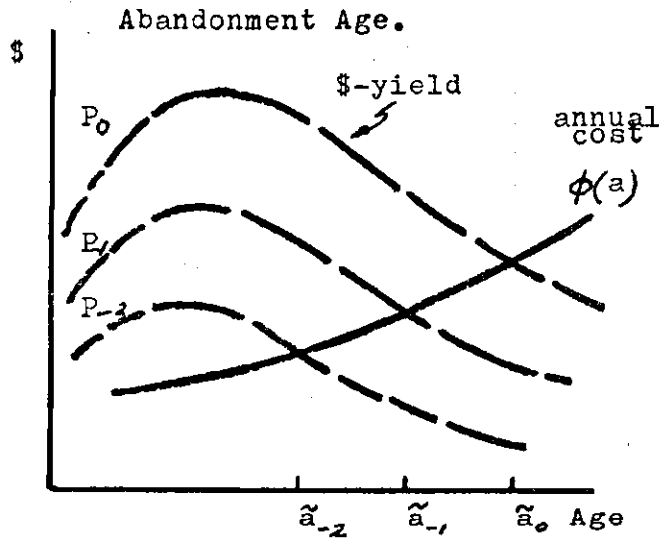


Figure B10. Abandonment Age.

dollar yield does not cover the additional cost of cultivation, i. e. for  $a > \tilde{a}_0$   $\Phi(a) > P_0 y(a)$ . Therefore, at a given price, there exists an age beyond which it is not profitable to cultivate the older trees. Thus, an abandonment age  $\tilde{a}$  can theoretically be obtained from:

$$\Phi(\tilde{a}) = P y(\tilde{a})$$

The Abandoned Fraction of Trees (ABFRT) depends on the age of abandonment  $\tilde{a}$ . Generally, the age composition of the stock of trees owned by the farmers, varies in response to past price developments and the farmer's previous planting and removal decisions. During periods of high and increasing prices a farmer tends to cultivate most of his trees and also, will plant new trees more

frequently and in larger quantities; hence, the proportion of young and productive trees tends to be higher during these years than the proportion of older and low yield trees, i. e. the average age of the total stock of trees will look younger. On the other hand, as prices decay, the planting of new trees gradually diminishes while the removal of old trees does not suffer major change. Thus, with low prices, the average age of the total stock of trees tends to get older. Therefore, during the whole 32 year price cycle the average age of the trees shifts from young to older ages. The two diagrams below show both the frequency distribution and the cumulative distribution of the stock of trees at varying prices. In Figure B11-a  $P_0$  is a high price which has prevailed during several years; therefore, a larger fraction of the trees tends to be young. On the other hand, as prices decrease to  $P_{-1}$  and  $P_{-2}$ , and stay there for some time, age distribution shifts to the right and shows peaks at older ages  $\bar{a}_{-1}$  and  $\bar{a}_{-2}$ , respectively. Furthermore, the cumulative distribution of trees in Figure B11-b gives the proportion of trees which are younger than a certain age  $a$ . At sustained high prices (the  $P_0$  curve) it is more likely to find a higher fraction of younger trees, than say, at a lower price  $P_{-2}$ . However, as one covers all the spectrum of different ages, the total proportion of trees with these ages should approach 100%, i. e. the total stock of trees. This is why all the curves shown cluster together as they reach the 100% limit.

Figure B11-b, admits a further and important interpretation. If  $\tilde{a}_{-1}$  is the abandonment age at a level of prices  $P_{-1}$ , then the segment AB is the proportion of trees whose age is older than the abandonment age  $\tilde{a}_{-1}$ . A rational farmer

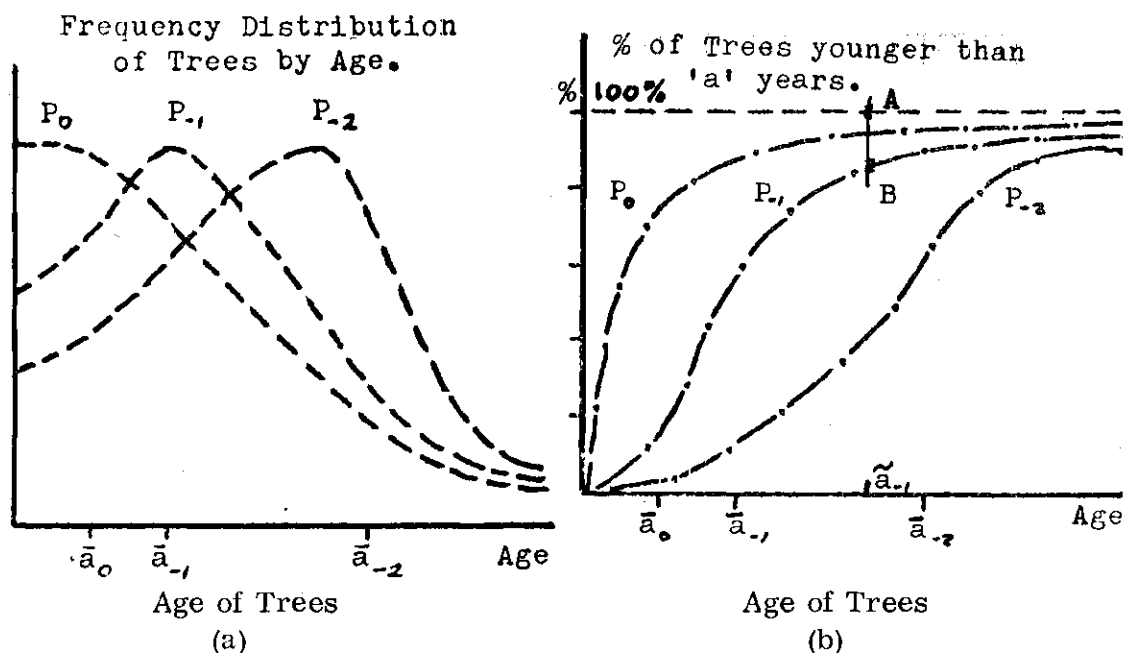


Figure B11. Distribution of Trees by Age at Varying Prices.

will not cultivate this fraction of trees. Thus, AB is the Abandoned Fraction of Trees (ABFRT).<sup>7)</sup>

<sup>7)</sup> Thus, far, the theoretical development of the abandonment function would be as follows:

Let  $w_p(a)$  = the number of trees of age  $a$ , given a price  $P$ .

$Py(a)$  = the dollar-yield of each tree in this group.

$\Phi(a)$  = the cultivation cost (labor and fertilizer) per tree of age  $a$ .

$\tilde{a}$  = the 'optimal' abandonment age.

Also, if the farmer only abandons trees whose yield is declining, as claimed by Arak [1, p. 212] and others,

$$\dot{w}_p(a) < 0, \dot{y}(a) < 0, \dot{\Phi}(a) > 0 \quad (a)$$

Then, the profit  $\pi$  during each year becomes:

Figure B12 combines the previous concepts in order to graphically develop a meaningful abandonment function. At a price  $P_0$  there is an abandonment age  $\tilde{a}_0$  and also a fraction of trees to neglect, given by point A. Similarly, at lower prices  $P_{-1}$  and  $P_{-2}$ , these correspond to abandonment ages  $\tilde{a}_{-1}$  and  $\tilde{a}_{-2}$ , and abandonment fractions given by points B and C, respectively (Figures B12 c and b). The solid line on Figure B12-b shows the abandonment function as one reads the ordinate scale from top to down. Tipping off the figure, he gets the percent

$$7) \quad \pi = \int_0^{\tilde{a}} P w_p(\tilde{a}) y(a) da - \int_0^{\tilde{a}} \Phi(a) w_p(a) da \quad (b)$$

$$\frac{d\pi}{d\tilde{a}} = P w_p(\tilde{a}) y(\tilde{a}) - \Phi(\tilde{a}) w_p(\tilde{a}) = 0 \quad (c)$$

$$\text{and } P y(\tilde{a}) = \Phi(\tilde{a}) \quad (d)$$

which is a maximum, in view of  $d^2\pi/d\tilde{a}^2 < 0$ , after using assumptions (a).

From (d) one can get  $\tilde{a}$ , and obtain the number of abandoned trees as follows:

$$\text{Abandoned Trees} = \int_{\tilde{a}}^{\infty} w_p(a) da.$$

Further, in Figure B10,  $\Phi(a)$  cuts the dollar-yield in two points. The younger age may not be an optimal point; in this case,  $\dot{y} > 0$ ,  $\dot{\Phi} < 0$ , but  $\dot{w}_p$  may be positive or negative depending on the frequency distribution of the trees age; hence  $\frac{d^2\pi}{d\tilde{a}^2}$  could have any sign.



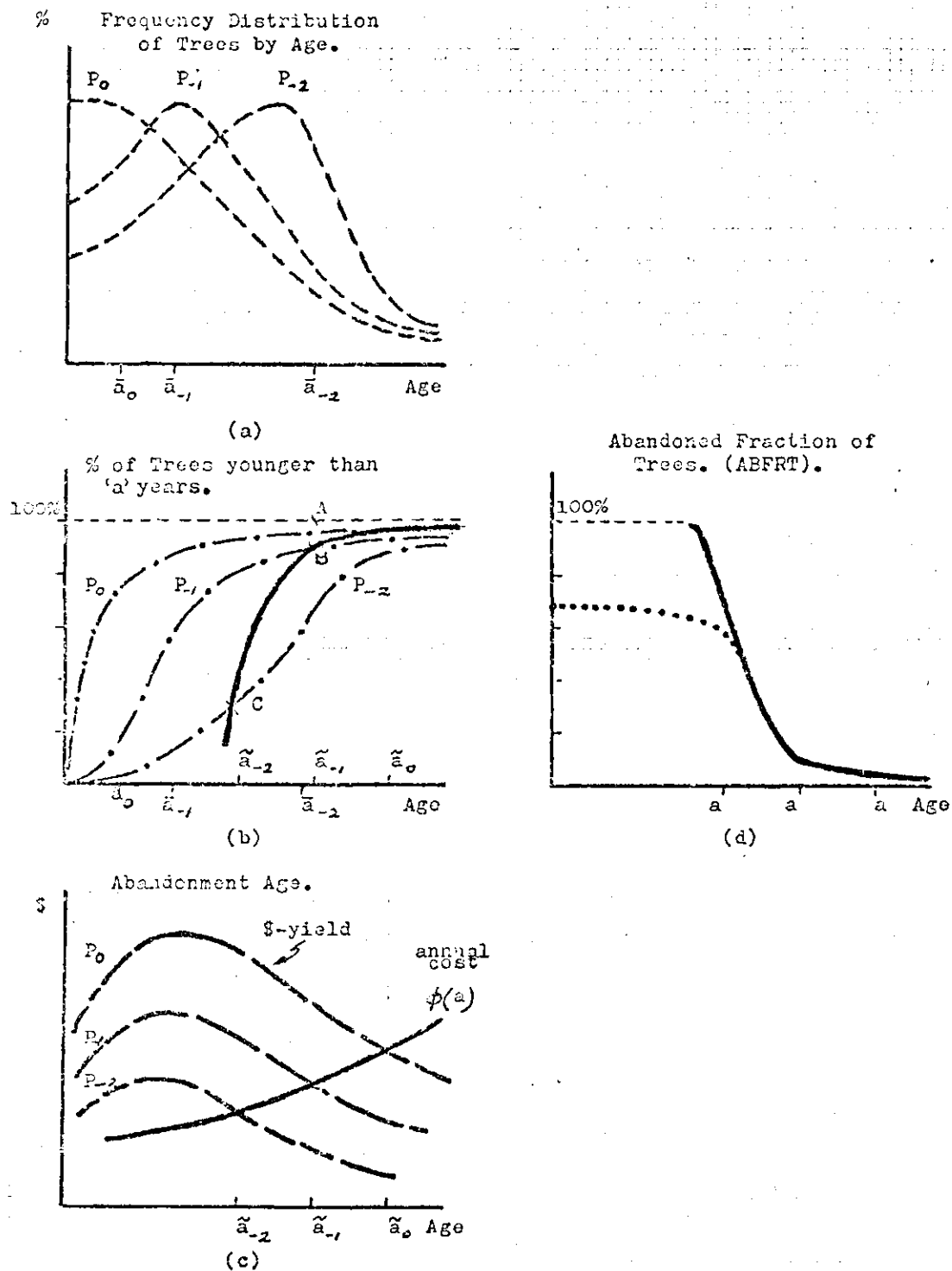


Figure B12. Construction of Abandonment Function.

of abandoned trees as a function of the abandonment age, as in Figure B12-d.

Figure B12-a shows the frequency distribution of the trees' age, together with the average age of the total stock of trees, i. e.  $\bar{a}_0$ ,  $\bar{a}_{-1}$  etc. At high prices ( $P_0$  curves) the abandonment age  $\tilde{a}_0$  is too far from the average age  $\bar{a}_0$ . However, as price declines, the abandonment ages rapidly approach the average age of the total stock of trees. In particular, the diagram shows, that at the lowest price  $P_{-2}$ , the abandonment age  $\tilde{a}_{-2}$  is less than the average age  $\bar{a}_{-2}$ . Very unlikely, a farmer will be willing to abandon average age stock of younger and productive trees. Therefore, as the abandonment age approaches the average stock age, the percent of abandoned trees rapidly bends toward the left as shown by the dotted line on Figure B12-d.<sup>8)</sup> Consequently, it will make more sense to represent this variable as a function of the difference between the abandonment age and the average age of the stock of obsolete capacity, as presented in Figure B13, where ABAGE is the abandonment age and AAOT is the average age of the older stock.

Equations 61 to 64 present the DYNAMO formulation of the process just described in this section and graphically presented in Figures B12 and B13.<sup>9)</sup>

---

<sup>8)</sup> Geer [13, p. 52] claims that abandonment rates in Brazil run as high as 50% of the obsolete trees, during period of low prices. This abandonment fraction would correspond to an abandonment age less than the average age of the total stock of trees.

<sup>9)</sup> The price-yield is approximated by the product of the domestic price to the former ADPR and the average yield (AYTT). Thus,  $MSCOST \sim \Phi(a)$ . Therefore, it follows  $a = ABAGE \approx f(MSCOST)$  as given by [62]. The rest of the equations follow in a straightforward way.

$$A \quad \text{MSCOST.K} = \text{ADPR.K} * \text{AYTT.K} * 10^{-3} \quad (61)$$

$$A \quad \text{ABAGE.K} = \text{TABHL}(\text{TABA}, \text{MSCOST.K}, 0.032, 0.0945, 0.0125) \quad (62)$$

$$T \quad \text{TABA} = 17/20/25/30/35/40$$

$$A \quad \text{RAGD.K} = (\text{ABAGE.K} - \text{AAOTK}) / \text{AGSD} \quad (63)$$

$$C \quad \text{AGSD} = 1$$

$$A \quad \text{ABFRT.K} = \text{TABHL}(\text{TABT}, \text{RAGD.K}, -20, 20, 5) \quad (69)$$

$$T \quad \text{TABT} = 0.7/0.65/0.60/0.55/0.50/0.40/0.20/0.18/0.15$$

- \* MSCOST - Maximum Supportable Cost (\$/Tree/year)
- AYTT - Average Yield of Total Trees  
( $10^{-3}$  Bags/Tree/year)
- ADPR - Average Domestic Price (\$/Bag)
- \* ABAGE - Abandonment Age (Years)
- RAGD - Relative Age Differential  
(Dimensionless)
- AGSD - Age Significant Difference (Years)
- \* ABFRT - Abandoned Fraction of Trees (%)

#### 16. Production Rate (PRR) and Producer Stocks of Green Coffee (PCSGC)

The annual production of green coffee is the sum of the production supplied by the maturing trees (MATR), the highly productive trees (HATR) and the non abandoned obsolete trees (OBTR(1-ABFRT)). This is shown in equation 65, where production rate (PRR) is given in Million of Bags per year as it usually appears in coffee bulletins.

Coffee which is produced in a year, is not immediately distributed to consumer centers. Before distribution, the picked berries are washed, dried, selected by quality and shape, packed in bags and finally mounted on mules or equivalent transportation means, to deliver at several warehouse centers. This

is the meaning attached to the variable called Distributed-Production-Rate (DPRR) in equation 66 where a distribution delay of one year elapses before the green coffee passes to enlarge the marketable stocks.

Several groups and institutions held stocks of green coffee. The farmers themselves may retain a portion of his crop if they think prices will go up; the domestic processors and roasters have to maintain adequate coverage to normally perform their operations; also and more importantly, private export houses and official institutions as well normally tend to hold large stocks. The aggregation of all of these stocks is given by the variable defined as Producer-Countries-Stocks-of-Green-Coffee (PCSGC).<sup>10)</sup> The level of stocks at the end of a year, is equal to the level of stocks one year before, plus the production added to the stocks (DPRR) minus the exports and domestic usage during the year (GCER + GCDUR) as shown by equation 67.<sup>11)</sup>

$$R \quad PRR.KL = \{ MATR.K * EYMT.K + HPTR.K * EYPT.K + OBTR.K * EYOT.K * (1 - ABFRT.K) \} * 10^{-6} \quad (65)$$

$$R \quad DPRR.KL = DELAY3(PRR.JK, CDDD) \quad (66)$$

$$C \quad CDDD = 1$$

---

<sup>10)</sup> A sizeable portion of these stocks is owned by the official coffee institutions of Brazil, Colombia, Mexico and other countries. The purpose has been to diminish the influence of the private exporter, thus creating favorable conditions to administer nationwide policies.

<sup>11)</sup> The listing of equations at the back of the appendix includes two additional rates in the equation for stocks. These were included there to test a buffer stock policy. They are omitted here to make the text simpler.

$$L \quad PCSGC.K = PCSGC.J + DT * (DPRR.JK - GCER.JK - GCDUR.JK) \quad (67)$$

- \* PRR        - Production Rate (Green Coffee)  
                      (Million Bags/year)
- MATR    } Standing Trees (Maturing,
- HPTR    } - Productive, Obsolete)
- OBTR    } (Trees)
- EYHT    } - Effective Yields (Bags/Tree/Year)
- EYPT    }
- EYOT    }
- \* DPRR       - Distributed Production (M Bags/Yr.)
- \* CDDD       - Coffee Domestic Distribution Delay  
                      (Years)
- \* PCSGC       - Producer Countries Stocks of Green  
                      Coffee (Million Bags)

#### 17. Green Coffee Domestic Usage Rate (GCDUR)

Domestic annual usage of green coffee has two components. One, the domestic consumption rate, is simply the product of the population sector of the producer nations and the average consumption (of green coffee equivalent) per head. (First term of equation 68). The second component reflects the volume of coffee which each year is destroyed (to maintain world prices) or which after being stored during almost four years, becomes non usable. Equation 69 insures that stocks do not become negative, during periods of abnormally low stocks and very high domestic consumption.

During times of lower and declining prices, Brazil and the larger producer may destroy sizable amounts of their stocks with the purpose of supporting prices at the current level. This effect has been captured in the Coffee-Destruction-Multiplier (CDEM) as exhibited in Figure B14. In the diagram, rising or decaying prices lead to lower or higher quantities to destroy, respectively. At high prices

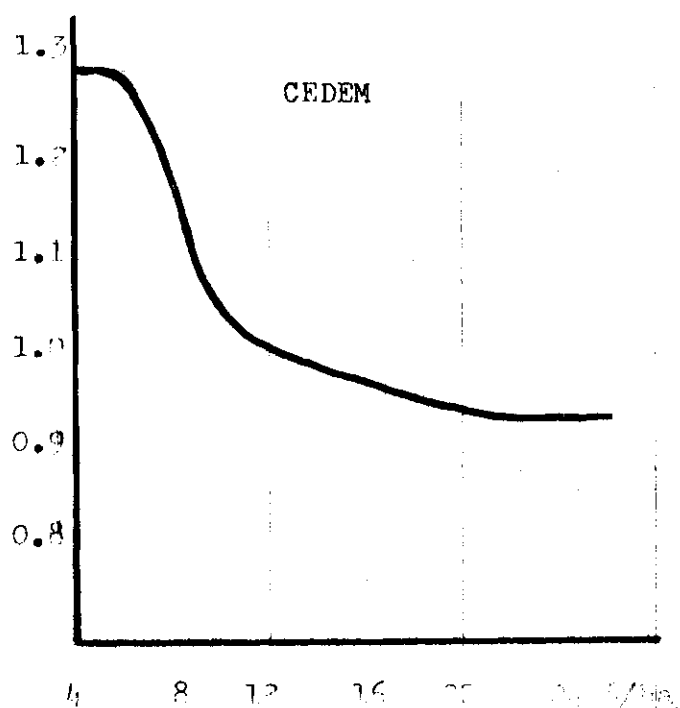


Figure B14. Coffee Destruction Multiplier as a Function of World Prices.

when the multiplier has reached a plateau, the nations do not have any strong motivation to eliminate coffee from the stocks; quite the contrary, they may even attempt to sell coffee of low quality in view of the general scarcity existing in the market; on the other hand, at the lowest prices, there always will be a maximum amount of coffee to destroy, beyond which the depressed cash position of the nation does not suffice to cover abnormally high destruction costs.<sup>12)</sup>

(See equation 20.)

<sup>12)</sup> Price change as well, may influence destruction of coffee. The listing of equations at the back of the appendix includes the effect of price change as PCHDEM, 'Price Change Destruction Multiplier.' Omission of this variable from the model did not alter behavior.

$$A \quad GCDURI.K = TLABF.K * AUPLU + PCSGC.K * CDEM.K / NDED \quad (68)$$

$$R \quad GCDUR.KL = \min(PCSGC.K / DT, GCDURI.K) \quad (69)$$

$$C \quad NDED = 4$$

$$C \quad AUPLU = 0.2 \times 10^{-6}$$

$$A \quad CDEM.K = TABHC(TCDE, AWPR.K, 6, 24, 2) \quad (70)$$

$$T \quad TCDE = 1.3 / 1.2 / 1 / 1 / 1 / 0.98 / 0.96 / 0.95 / 0.95$$

- \* GCDURI - Green Coffee Domestic Usage Rate Indicated (MBags/Yr)
- TLABF - Total Labor Force (Men)
- AUPLU - Average usage per Labor Unit (MBags/men-yr)
- PCSGC - Producer Countries Stocks (MBags)
- \* GCDUR - Green Coffee Domestic Rate (MBags/men-yr.)
- NDED - Normal Deterioration Delay (Years)
- \* CDEM - Coffee Destruction Multiplier (Dimensionless)
- AWPR - Average World Coffee Price (¢/lb.)

#### 18. Desired Producer Countries Stocks of Green Coffee

##### (DPCSGC) and Desired Export Quantity to Sell (DEXQS)

The producer nations have several good reasons to keep a target level of inventories such that stocks do not become too high and costly or too low to jeopardize efficient customer service, market share and foreign income. In the commodity market, and the coffee market in particular, stocks are kept to play several key roles. To list a few, there is a working stock to maintain the current volume of business. Second, there is a safety stock to insure proper customer service and income against sudden upsurges in demand. Not being

able to supply a customer properly and timely would mean a loss in market share and penetration. Third, increasing quantities of coffee supply and stocks would be required to increase market share penetration and income--a market strategic stock. Fourth, keeping additional reserves of green coffee will insure increased funds in case adverse weather or other random events damage some other country's crop--speculative stocks. Therefore, the total level of stocks kept by the producer nations could be described by the following composite function:

$$\begin{aligned} \text{Target Stocks} = & \text{Working Stock} + \text{Safety Stock} + \text{Market Strategic Stock} \\ & + \text{Speculative Stocks} \end{aligned}$$

$$\text{or} \quad \hat{S} = WS(\lambda) + SS(\sigma_{\lambda}) + MS(p\lambda) + SP(\sigma_p)$$

where

WS is a function of  $\lambda$ , the average usage per year.

SS is a function of the expected usage fluctuation,  $\sigma_{\lambda}$ .

MS is a function of desired income,  $P\lambda$ , where  $p$  is price.

SP is a function of expected price fluctuations.

Furthermore, at each level of stocks there exist an associated level of required investment and expenditures; these tend to grow very rapidly at higher levels of inventory.<sup>13)</sup> Therefore, the above equation can be recast as follows:

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<sup>13)</sup> Costs of building new and larger warehouses and equipment; the larger the warehouse, the higher the holding and maintenance costs. Furthermore, to increase market share penetration and sales, a flexible distribution network ought to be built, and stocks have to be decentralized to give proper service to



$$\hat{S} = \Phi(\lambda, p, \sigma_{\lambda}, \sigma_p; \text{cost})$$

where increases in usage  $\lambda$  or price  $p$ , or both, bring about funds requirements to increase the stocks held and expand the stocking facilities. Similarly, larger values of usage and price are normally associated with larger fluctuations in both demand and price.<sup>14)</sup> On the other hand, the increasing cost to support the additional stocks, present a restraint to further expansion. Hence, our postulated equation can be simplified as follows:

$$\hat{S} = \Phi(\lambda p - \text{cost})$$

where  $\lambda p$  is the foreign income received from coffee, and 'cost' is the expenditure required.

The above equation is a theoretical but realistic abstraction. The same equation translated into managerial language simply tells that the establishment of a desired level of stocks depends on the foreign income earned from coffee

---

<sup>13)</sup> the market. Decentralization of stocks is one of the primary causes of inflated costs.

<sup>14)</sup> Coffee data confirms this hypothesis. Our explanation to this situation follows: As prices rise, speculators are attracted to the market. Too many speculators in the future market generate additional short term fluctuations in daily quotations. (See Appendix C) As price fluctuation increases ( $\sigma$  is higher), traders will wish to increase their speculative stocks, therefore ordering larger quantities of green coffee. As prices decline, (one, two, or three years later) the trader would want to reduce again his level of stocks; he will order less quantities, thereby creating a fluctuation in demand to the producer.

exports, and also on the expenditures realized to support the coffee market share--the foreign cash position. Certainly, the foreign cash reserve is one of the variables which administrators look more closely at, before advancing inventory coffee policy. Thus, the dynamic version of the above relation would include in addition to income and expenditures, the previous performance of cash availability. Hence,

$$\hat{S}_t = \Phi(FCR_t)$$

$$FCR_t = FCR_{t-1} + (\text{Income} - \text{Expenditures}).$$

where  $FCR_t$  is the foreign cash reserve at the beginning of year  $t$ .

The establishment of a desired level of stocks is an important factor to administer and coordinate pricing and foreign income policies by the producers; policies which are, nonetheless, very different for both small and larger producers, as we can see shortly.

Equations 71 to 73 show the annual averages of domestic usage of green coffee, total world usage and production rates, respectively. The Desired-level-of-stocks (DPCSGC) is then, the product of the average total world usage (AGCUR) and the fraction of years the producer wants to cover with his stocks (equation 74). This number is the Desired-Producer-Year-Supply (DPCYS), a value which varies through time, but which on the average appears to be about 0.5 years for coffee ( $NP\text{CYS}=0.5$ ). Stated in a different way, a 0.5 years supply in coffee means that if production were to be stopped for some reason, the

producer nation still could supply coffee for half a year more, assuming demand stays constant.

Equation 75 shows the normal year supply (NPCYS) as influenced by a function of RFCRS, the Relative Foreign Coffee Reserve Supply. This is simply the name given to the countries' coffee foreign cash reserves. Figure B15 displays two possible relationships for this function, one indicates the effect cash position has on desired stocks if the producer is a small nation unable to alter price formation; the other curve depicts the response of a large producer, like Brazil. The curve followed by the small producer shows that as the foreign reserve deteriorates, perhaps as a result of low prices and high expenditures,

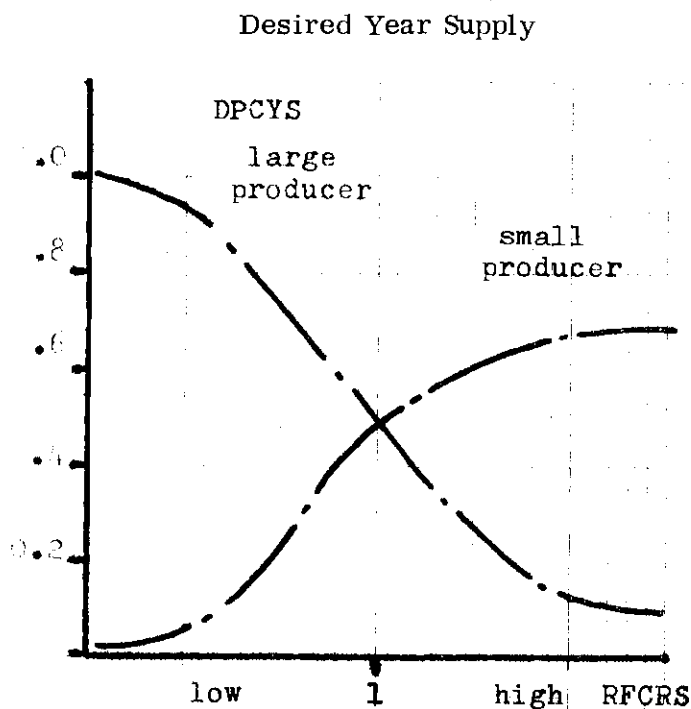


Figure B15. Effect of Foreign Cash Reserves on Coffee Policy.

the small producer, unable to alter world prices would tend to reestablish its cash position by selling more, thereby keeping less stock in the warehouses. On the other hand, a large producer nation, conscious of its ability to increase world prices by supplying less quantities to the market, will tend to increase the level of stocks, i. e. increasing the target years of supply.

Furthermore, the fact that at extreme values of foreign reserves, there always will be a minimum stock below which the producers would not be able to operate, and an upper limit to the stock accumulation beyond which the countries would be unable to store the grain in the limited size of their warehouses or get funds to build up enough of them, give weight to our hypothesized shape for both functions.

The Desired Export Quantity to Sell (DEXQS), is the amount of green coffee the producer nations would be willing to sell. It is then, equal to the exportable quantity plus or minus adjustments made on the stocks to achieve the desired level of stocks (DPCSGC). This is shown in equation 76. The first two terms (APRR-AGCDUR) show the exportable quantity, the amount left after subtracting the domestic usage from the average production. The second term shows the adjusting stock term. If stocks are greater than the target value, additional coffee will be offered to the customers; otherwise lesser quantities will be supplied. PCT is the correction time. A correction time equal to one year indicates that producers would want to achieve their desired levels of stock in just one year.<sup>15)</sup>

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<sup>15)</sup> Under International Coffee Agreements the Desired Export Quantity (DEXQS) is

$$A \quad AGCDUR.K = SMOOTH(GCDUR.JK, 1) \quad (71)$$

$$A \quad AGCUR.K = SMOOTH(GCER.JK + GCDUR.K, 1) \quad (72)$$

$$A \quad APRR.K = SMOOTH(PRR.JK, 1) \quad (73)$$

$$A \quad DPCSGC.K = AGCUR.K * DPCYS.K \quad (74)$$

$$A \quad DPCYS.K = NPCYS * TABHL(TDYS, RFCRS.K, 0, 2, 0.2) \quad (75)$$

$$T \quad TDYS = 1 \dots 1 \text{ (Constant in the standard model).}$$

$$C \quad NPCYS = 0.5$$

$$A \quad DEXQS.K = APRR.K - AGCDUR.K + (PCSGC.K - DPCSGC.K) / PCT \quad (76)$$

$$A \quad DPEXQ.K = DEXQS.K * QUOTA.K \quad (77)$$

- AGCDUR - Average Domestic Usage (MBags/Yr.)
- AGCUR - Average Usage (Domestic and Foreign) (MBags/Yr.)
- APRR - Average Production (MBags/Yr)
- \* DPCSGC - Desired Producer Countries Stocks of Green Coffee (MBags)
- DPCYS - Desired Producer Countries Year Supply (Years)
- NPCYS - Normal Prod. Countries Year Supply (Years)
- RFCRS - Relative Foreign Coffee Cash Reserve (Dimensionless)
- \* DEXQS - Desired Export Quantity to Sell (MBags/Yr)
- PCT - Producer Stocks Correction Time (Years)
- \* DPEXQ - Desired Producer Export Quantity (MBags/Year)

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<sup>15)</sup> further affected by establishing quotas in response to prices. The new desired quantity would be  $DEXQS * QUOTA$  as shown in the listing of equations at the back of the appendix. The new variable is called  $DEXPQ = DEXQS * QUOTA$ . See the description of the 1967 ICA in Geer [13, p. 20], or Rowe [24, p. 186] for generalities of the 1962 ICA.

## QUOTA - Export Quota (%)

### 19. Green Coffee Export Rate (GCER) and World Coffee Price (AWPR)

Meadows' Dynamic Commodity Cycle Model (DCCM) [42] assumes an inverse relationship between stock levels and prices. In particular, the DCCM describes prices as depending on the current inventory coverage, the current years supply for the commodity in question. This type of relation seems to hold most commodities, including coffee. A review of the patterns of behavior exhibited by coffee production, producer stocks, exports and coffee prices in chapter will reveal to the reader the fact that increasing and higher stocks normally result in lower and declining prices and vice versa.

Meadows' model, on the other hand, tacitly assumes that all the existing stock is 'saleable' in the sense that a producer, unable to directly affect price developments, will always sell as much as he can at the time, and then will adjust his production to maintain his desired stock coverage. In the case of coffee, this assumption is not correct. The larger producers acting independently or jointly with smaller producers have frequently held a portion of their stocks, to force an increase in prices, and then have sold a reduced amount at a much higher price. Therefore, although the price-inventory coverage relationship appears a statistically correct relation for coffee, it seems that it does not fully capture the underlying mechanisms by which both producers and traders meet together to pact how much to export and at what price. We hope that adding detail to the model will serve its purpose in designing stabilization policies.

The quantity of coffee to be exported, together with its price, are both agreed jointly and at the same time by each producer and user. Each producer offers to sell a certain quantity, say DPEXQ, while each user-traders, roasters, processors, etc. offers to buy an amount (DTIMQ) at the current prices. If the two quantities are the same, the deal will close and the amount will be sold at actual prices. However, if supplies exceed demand, producers will offer discounts to induce traders to buy more; the larger the excess, the higher the discount. Therefore, as traders buy more, prices decline. On the other hand, if production has been low or high quotas are enforced, traders' demand can be higher than supplies. Hence, traders will be willing to pay a premium on the price to get their full requirements; thus prices will tend to rise, on the condition that producers gradually release higher quantities from their stocks to the traders. Thus, the quantity 'pacted' should lie somewhere in between the original offer and the original demanded quantity, a simple average between the two may be a good approximation (Equation 78). Similarly, the 'pacted' price depends on the difference between the two original quantities, as shown in Figure B16 and equations 79 and 80.

As shown in the figure, the shape of the World Price Multiplier (WPRMA) may take several forms, depending on how sensitive is the market to different levels of under/over supply. The solid line shows the function used in the basic computer runs.

$$\begin{array}{ll}
 \text{A} & \text{GCERI.K} = \text{SMOOTH}\{(\text{DPEXQ.K} + \text{DTIMQ.K})/2, 1\} \\
 \text{R} & \text{GCER.KL} = \text{MIN}(\text{PCSGC.K}/\text{DT}, \text{GCERI.K})
 \end{array} \quad \left. \vphantom{\begin{array}{l} \text{A} \\ \text{R} \end{array}} \right\} \quad (78)$$

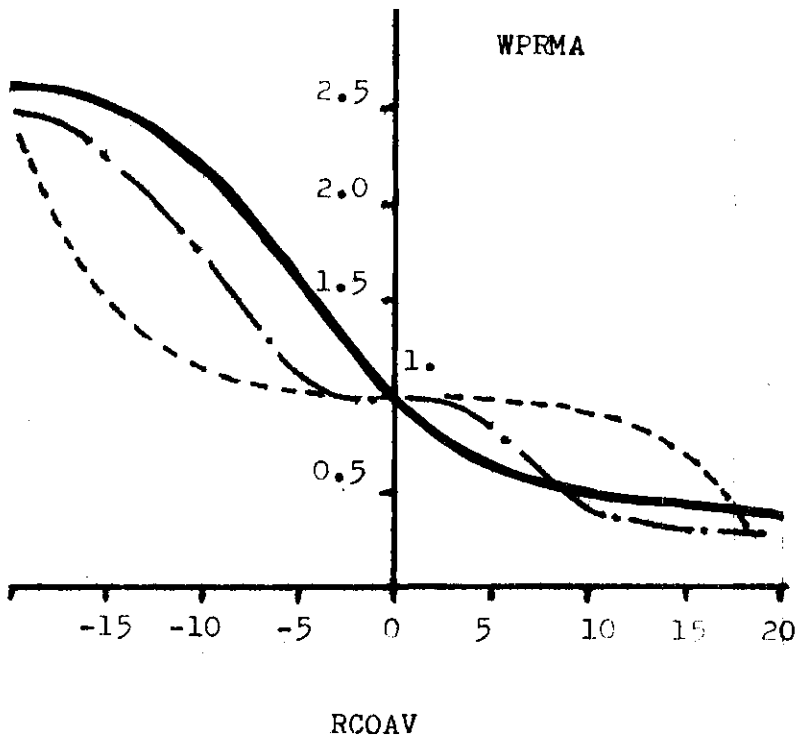


Figure B16. Relative Coffee Availability  
and World Price Multiplier.



$$A \quad RCOAV.K + (DPEXQ.K - DTIMQ.K) / AVSD \quad (79)$$

$$C \quad AVSD = \$1$$

$$A \quad WPRMA.K = TABHL(TWPR, RCOAV.K, -20, 20, 5) \quad (80)$$

$$T \quad TWPR = 2.6 / 2.5 / 2.2 / 1.6 / 1 / 0.6 / 0.5 / 0.45 / 0.4$$

$$A \quad WPRI.K = NORPRI * WPRMA.K * WPRMFP.K \quad (81)$$

$$C \quad NORPRI = 12$$

$$A \quad AWPR.K = SMOOTH(WPRI.K, 1) \quad (82)$$

GCER	- Green Coffee Export Rate (MBags/Year)
DPEXQ	- Desired Producers Export Quantity (MBags/Year)
DTIMQ	- Desired Traders Import Quantity (MBags/Year)
RCOAV	- Relative Coffee Availability (Dimensionless)
AVSD	- Availability Significant Difference (MBags/Year)
NORPRI	- Normal World Price (¢/pd)
WPRMA	- World Price Multiplier from Availability (Dimensionless)
WPRMFP	- World Price Multiplier from Future Market Price (Dimensionless)
AWPR	- Annual Average World Price (C/lb.)

## 20. Domestic Price to the Farmer (ADPR)

The price paid to the farmer in return for his bags of green coffee is a fraction of the current world average price. To carry out domestic price policy, the governments have established a wide range of complex mechanisms whose common purpose is to allow the official institutions to collect a portion of the foreign coffee earnings to implement various developmental programs throughout the nation. A brief description of the three most frequently used mechanisms

follows.

The exchange rate procedure is a system whereby the foreign receipts to the farmer (i. e. in dollars) are officially exchanged into domestic currency at a rate lower than the international current exchange rate. The tax in 'especie' ask the farmer to submit to the official coffee institutions a bag of coffee or a portion of it, for each bag sold in the international market. Finally, the establishment of a floor price on all excess output which the official institutions would buy if no other purchaser appears, has the effect of tuning domestic prices above and around this minimum price. Each one of the above regulations together with several others, have been used by most producer nations at one time or another.<sup>16)</sup>

Despite the frequent and erratic changes in domestic price policy and complex apparatus, analysis of data clearly shows a well established pattern of domestic prices with respect to world prices. Geer [13, p. 59 and 81] has studied the relationship between the two prices during the Fifties for the Brazilian and Colombian cases. More recently Keith [21, p. 304] has analyzed the net returns traditionally received by the Colombian coffee farmer with respect to the world coffee price, after proper consideration of the taxes, and cultivation costs paid, and over a longer period of years (1918-1973). The two analyses clearly show a

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<sup>16)</sup> The reader may find a fairly complete description of the type of regulations most frequently used in Geer [13, p. 57-65]. Rowe [24], [25] gives a description of the evolution of these coffee policies since the beginning of the century, in most of the coffee producer nations. Netto [21, p. 76-105] presents coffee policy within the Brazilian context. Kalmanoff [16, p. 65] describes the regulations established by the Colombian governments during the last twenty years.

direct relationship between Average Domestic Price (ADPR) and Average World Price (AWPR), and present evidence that as the world price rises to high values, domestic prices increase at a lower rate, as shown in Figure B17.

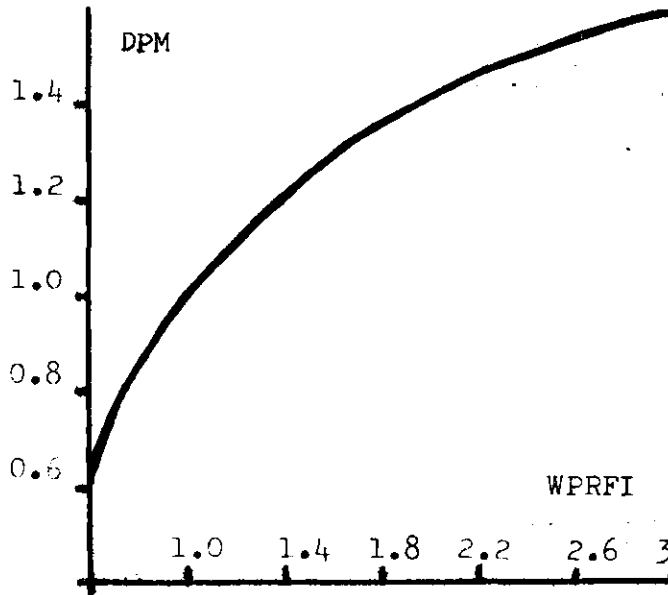


Figure B17. Relationship Between World Price and Domestic Price to the Farmer (The Domestic Price Multiplier).

In the figure, the horizontal axis shows a normalized world price, the World-Price-Fluctuation-Index (WPRFI) which is the ratio between the average world price (AWPR) and the normal world price (NORPRI); the vertical axis is the Domestic-Price-Multiplier (DPM), Equations 83 and 84.

The Domestic Price (DPRI) is given in \$/Bag, and is the product of the

average world price (AWPR) and a fraction given by the product  $DPM \times NDPM$  ( $NDPM = 0.5$ ). This fraction converts world price in \$/Bag,  $(AWPR \times 1.32)$  into domestic price; it could be as low as  $0.6 \times 0.5 = 0.3$  or as high as  $1.6 \times 0.5 = 0.8$  (See Figure B17). The annual Average Domestic Price is given by the smooth operator in equation 86. Equation 87 presents the fractional change in domestic price, a variable required to get one of the two land multipliers (LPCHM) in section 4 of this appendix.

$$A \quad WPRFI.K = AWPR.K / WORPRI \quad (83)$$

$$A \quad DPM.K = TABHL(TDOP, WPRFI.K, 0.6, 3, 0.4) \quad (84)$$

$$T \quad TDOP = 0.6/1/1.2/1.3/1.4/1.5/1.6$$

$$A \quad DPRI.K = AWPR.K * 1.32 * DPM.K * NDPM \quad (85)$$

$$C \quad NDPM = 0.5$$

$$A \quad ADPR.K = SMOOTH(DPRI.K, 1) \quad (86)$$

$$A \quad DPRCH.K = (DPRI.K - ADPR.K) / ADPR.K \quad (87)$$

- WPRFI - World Price Fluctuation Index  
(Dimensionless)
- \* DPM - Domestic Price Multiplier  
(Dimensionless)
- DPRI - Domestic Price Indicated (\$/Bag)
- WDPM - Normal Domestic Price Multiplier  
(Fraction)
- \* ADPR - Average Domestic Price (\$/Bag)
- \* DPRCH - Domestic Price Change (Fraction)

## 21. Foreign Coffee Cash Reserves (FCR)

The Foreign-Coffee-Cash-Reserves at the end of a year equal the amount held one year before, plus the foreign coffee income (FCEAR) earned during the year, minus the expenditures made over the same period (FCRDR), Equation 88.

Foreign-Coffee-Earnings (FCEAR) is the product of the Average World Price (AWPR) and the Annual Average of Green Coffee Exports (AGCE), Equation 89.

The representation of the total expenditures during the year (FCRDR) is somewhat more complex. As indicated by equations 90, it consists of two terms. The first one is the normal amount of disbursements (FCRNE) which depends on both the total expenditures required to support the total population of the country(s) i. e.  $TLABF \cdot NEXLU$ ; and the fraction of these expenditures provided by coffee (COFP). Furthermore, the Expenditures per Labor Unit (NEXLU) increase as the country develops. Thus, the normal expenditure (FCRNE) is a rising function of the Development Index (DEVIN). The second term in equation 90 adjusts the available cash to a normal (target) value. The target value is the amount of cash normally kept as countries' foreign reserves; a 0.3 years of cash supply appears to be a reasonable choice. This latter term can be at times positive, at times negative. If cash reserves are below the target value, expenditures will be curtailed until balance could be reestablished. On the other hand, if cash availability surpasses the target, pressures will develop to use the excess, thereby expenditures will tend to rise. The Foreign Reserve Correction Time (FRCT) indicates the velocity at which administrators want to achieve a balanced cash position.

$$L \quad FCR.K = FCR.J + DT * (FCEAR.JK - FCRDR.JK) \quad (88)$$

$$A \quad AGCE.K = SMOOTH(GCER.JK, 1) \quad \left. \vphantom{\begin{matrix} A \\ R \end{matrix}} \right\} \quad (89)$$

$$R \quad FCEAR.KL = TLABF.K * AGCEF.K * 1.32 * 10^6$$

$$A \quad FCRNE.K = TLABF.K * COFP.K * NEXLU * DEVIN.K / 50 \quad \left. \vphantom{\begin{matrix} A \\ R \end{matrix}} \right\} \quad (90)$$

$$R \quad FCRDR.KL = FCEAR.K + (FCR.K - FCRNE.K * NFCRYS) / FRCT$$

$$C \quad NFCRYS = 0.3$$

$$C \quad FRCT = 0.6$$

$$C \quad NEXLU =$$

- \* FCR - Foreign Coffee Cash Reserves (\$)
- AGCE - Annual Average Green Coffee Export Rate (M Bags/Yr)
- \* FCEAR - Foreign Coffee Earnings Rate (\$/Yr)
- AWPR - Average World Coffee Price (¢/lb.)
- $1.32 \times 10^6$  -  $AWPR \times 1.32$  to get price in \$/Bag;  
 $10^6$  to convert AGCE in Million Bags/yr. to Bags per year.
- \* FCRNE - Normal expenditures (\$/Yr)
- TLABF - Total Labor Force (men)
- COFP - Percent of Coffee Participation in Expenditures (%)
- NEXLU - Normal Expenditures per Labor Unit (\$/Men)
- DEVIN - Development Index (Dimensionless)
- 50 - Initial Development Index Used to Normalize DEVIN
- \* FCRDR - Disbursement Rate (Total Expenditures) (\$/yr)
- NFCRYS - Normal Foreign Coffee Reserves Year Supply (Years)
- FRCT - Foreign Reserves Correction Time (Years)

## 22. Development Index (DEVIN) and Coffee Participation (COFP)

The Development Index (DEVIN) of the coffee producing nations represents the level of economic and industrial progress of these nations. During the early years of the century the coffee nations had to import almost all the required capital to generate sustained growth. Thus, foreign earnings from coffee were of salient importance to progress. However, as the countries develop, the influence of coffee, although still very important, gradually tends to diminish, in view of newly created alternative sources of foreign income and a higher level of technical capability.

Equations 91 and 92 show the Averaged-Foreign-Coffee-Earnings (AFCER) and the Total-Foreign-Earnings (TFEA), respectively. This variable is the ratio between the former, (AFCER) and the percent of total foreign earnings provided by coffee exports (COFP). Initially, this percent is made equal to 70%, gradually as the countries develop, it will decay to 40% by the seventies. Equation 95 shows the Relative-Foreign-Earnings-per-Labor unit (RFEPLU). This research assumes that a larger amount of foreign earnings per head, tends to impulse the purchase or development of capital to enhance industrial progress. This is the meaning attached to the variable Foreign-Earnings-Growth-Multiplier depicted by equation 94 as a linear function of the earnings per head <sup>17)</sup> and

---

<sup>17)</sup> This function,  $FEGMI = \Phi(RFEPLU)$ , can conceptually have many different shapes. It could be exponential or 'S' shaped; each country may as well exhibit a different pattern. However, the linear assumption taken here does not imply that the development index (DEVIN) to be explained later, follows a linear pattern. Quite the contrary, the index follows the exponential pattern observed in most nations (See equation 96), i.e.

then smoothed in equation 95. Here a delay of four years has been assumed to account for the selection, purchase and proper use of the imported (or internally developed) technologies.

The Development Index (DEVIN) at the end of a year  $t$ , is equal to the index at  $t - 1$ , plus the change occurred during the year (DEVR).  $DEVIN = 50$  means that at the beginning of the century a level of development of 50 'units' prevailed throughout the coffee nations, equation 96.

The Development Rate (DEVR) depends on the current development index (DEVIN) and also on the Foreign Earnings Growth Multiplier (FEGM); equation 97, simply shows that at higher levels of development, additional development tends to be self induced which results in exponential growth. The effect of the FEGM multiplier is then to adjust the normal exponential growth of the development index to lower or higher rates, depending on both, the amount of foreign coffee earnings and the population needs.

Figure B18 shows the participation of coffee in the total foreign earnings of the producing countries. Initially, at low levels of development, coffee plays a key role in promoting growth. Also, at these initial phases of development, the country is not able yet to generate enough industrial products of high quality to export and earn additional foreign income. Thus, Coffee Participation (COFP)

---

17)

$$\frac{d}{dt}(\text{DEVIN}) = k(\text{DEVIN})$$

$$\text{DEVIN} = C_0 e^{kt}$$

where  $k$  includes the postulated linear relation, among other things.



stays high enough while the Development Index (DEVIN) gradually rises. Later, further increases in the index, brings about the resources, capital and technological capability to produce a variety of alternative exports which increase the total foreign receipts and make the nation less dependent on coffee to achieve its development goals. Hence, COFP decays to lower values (equation 98). The values attached to COFP have been adjusted from figures provided by the Pan American Coffee Bureau [29, 30, 31].

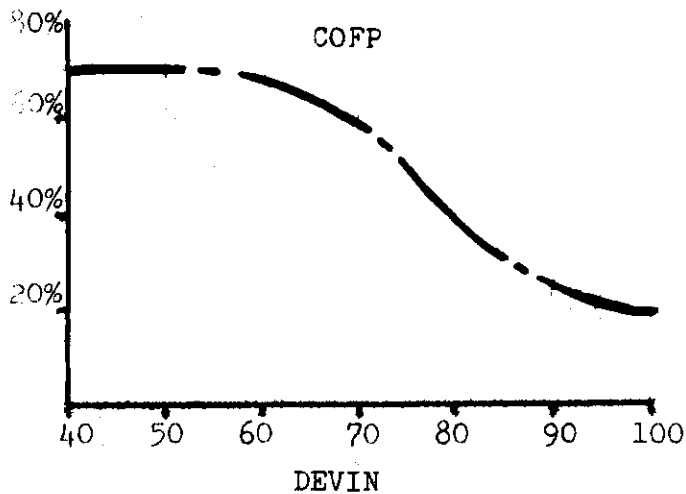


Figure B18. Percent of Foreign Earnings Provided by Coffee as a  
Function of Development Index.

A	AFCEP.K=SMOOTH(FCEP.JK, 2)	(91)
A	TFEA.K=AFCEP.K/COFP.K	(92)
A	RFEPLU.K=TFEA.K/(TLABF.K*NFEPLU)	(93)
C	NFEPLU=70	
A	FEGMI.K=TABHL(TFEG, RFEPLU.K, 0.8, 2, 0.2)	(94)
T	TFEG=0.5/1/1.05/1.1/1.15/1.2/1.25/	
A	FEGM.K=SMOOTH(FEGMI.K, 4)	(95)
C	DEVIN.K=DEVIN.J+DT*DEVR.JK	(96)
N	DEVIN=50	
R	DEVR.KL=DEVIN.K*FEGM.K*NGRW*GROWTH.K	(97)
C	NGRW=0.007	
A	COFP.K=TABHL(TCFP, DEVIN.K, 50, 100, 10)	(98)
T	TCFP=0.70/0.68/0.60/0.40/0.25/0.20	

	AFCEP	-	Average Foreign Coffee Earnings (\$/yr)
	TFEA	-	Total Foreign Earnings (\$/yr)
*	RFEPLU	-	Relative Foreign Earnings per Labor Unit (Dimensionless)
	TLABF	-	Total Labor Force (men)
	NFEPLU	-	Normal Foreign Earnings per Labor Unit (\$/men-yr)
	FEGMI	-	Foreign Earnings Growth Multiplier (Indicated) (Dimensionless)
*	FEGM	-	Foreign Earnings Growth Multiplier (Dimensionless)
*	DEVIN	-	Development Index (Dimensionless)
*	DEVR	-	Development Rate (Fraction/year)
	NGRW	-	Normal Growth (Fraction/year)
	GROWTH	-	A Test Variable to Introduce Growth After 1890
*	COFP	-	Coffee Participation (Fraction)

### 23. Attraction to Urban Centers (ATUC)

Section 1 of this appendix described the Migration Rate from rural areas to urban centers as depending on both the total pool of agricultural workers (ALABF) and also on the attractiveness posed to the peasant by the living conditions in the city (ATUC). We have assumed that the peasant Attraction-to-Urban Centers (ATUC) rises with the Development Index (DEVIN) as displayed by Figure B19. The assumption is reasonable, in the sense that developmental policies are normally tuned to generate industrial growth, which require the concentration of individuals in cities to fill the new manufacturing jobs. This in turn requires the expenditure of sizeable investments in housing, schools, and

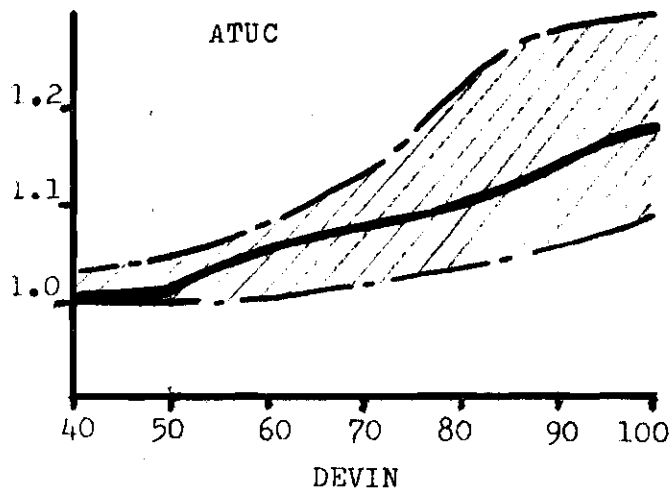


Figure B19. Attraction to Urban Centers as a Function  
on Development Index.

many other services, factor whose effect is to attract labor to the cities, as confirmed by demographic sources.

The shape of this relationship may be exponential tending to level off, i.e. the Sao Paulo area, or exponential but almost linear as may occur in several African cities. The shaded area in the figure shows a possible region of operation for this variable. The solid line is the function assumed in this research.

$$A \quad ATUC.K = TABHL(TMUC, DEVIN.K, 50, 100, 10) \quad (99)$$

$$T \quad TMUC = 1/1.05/1.08/1.1/1.12/1.14$$

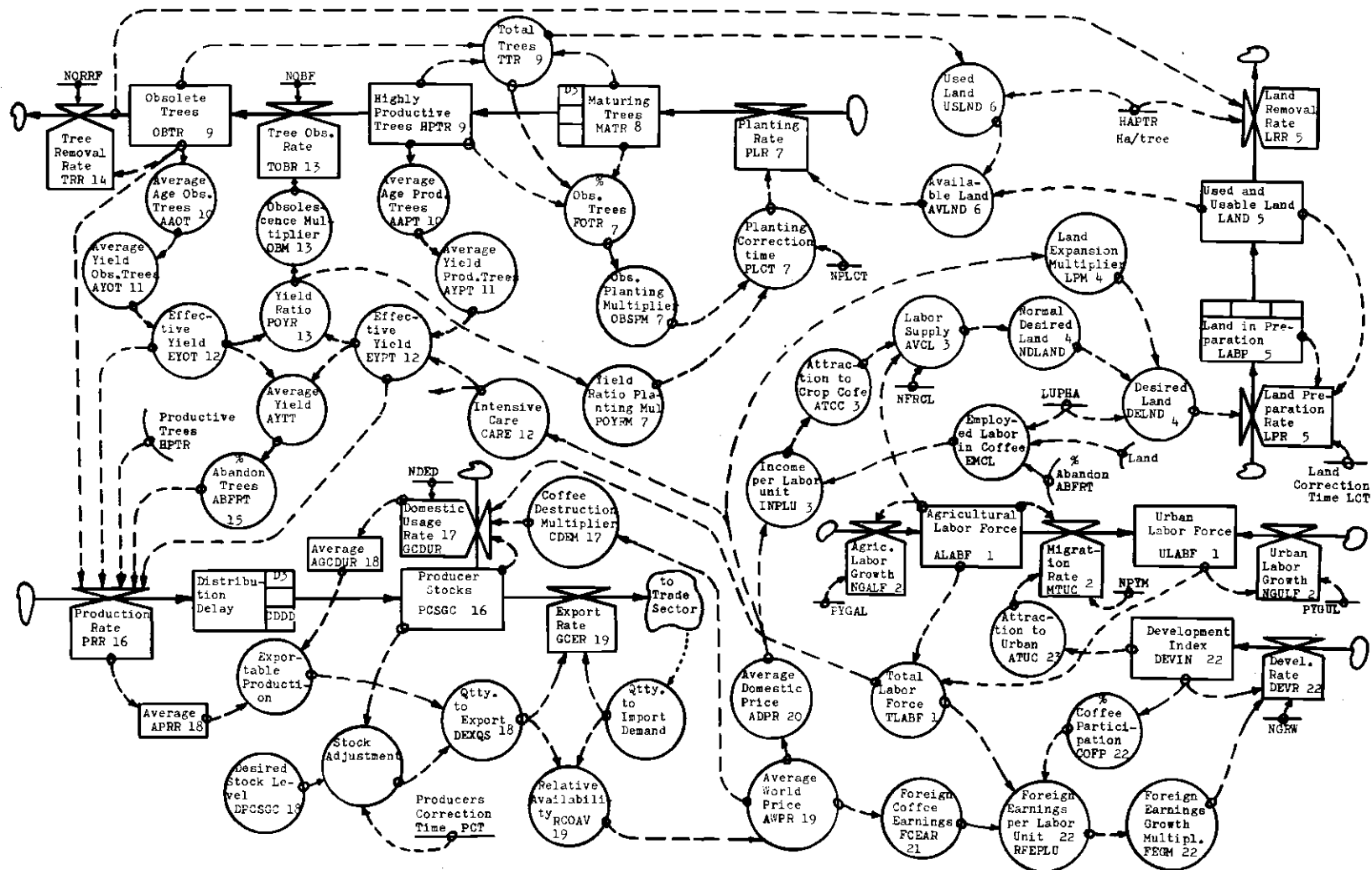


Figure B20. Production Sector DYNAMO Model.

## APPENDIX B-II

### THE COFFEE TRADE AND FUTURE

#### MARKET SECTOR

#### DESCRIPTION OF EQUATIONS

#### ASSUMPTIONS AND SUPPORT

## II. TRADE AND FUTURE MARKET SECTOR

### 1. Traders' On-Hand and On-Order Stocks (TOHSGC, TOOSGC)

The stock of green coffee physically inside the traders' warehouse is on-hand stock. The amount of coffee already purchased but not arrived is on-order stock. The amount on order at the end of a period of time is then equal to the amount in the pipeline one period ago, plus the amount purchased (GCER) minus the amount physically entering the warehouse (AGCER) over the period in question (DT); in our case  $DT = 0.015625$  years. Similarly, the stock on hand (TOHSGC) at the end of week  $t$  is equal to the stock on hand at the end of week  $t-1$ , plus the amount arriving during the period (AGCER), minus the quantity sold (PUR) over the same period (equations 100 and 101).

The quantity sold per year, or Processor-Usage-Rate (PUR) is given by the Indicated-Usage-Rate (ICUR). This variable is the input to the World Coffee Model, which grows exponentially, as illustrated by world coffee consumption rates.<sup>1)</sup> In addition, weekly sales are limited by a maximum sales rate which depends on the current stocks on hand (TOHSGC/DT). If stocks account, say to 4 million bags of green coffee, the maximum possible sales rate is 4 million bags per week or  $4 \times 0.015625 = 256$  million bags per week (1 week  $\simeq 0.015625$  years). Therefore the Processor-Usage-Rate is then the minimum between the indicated

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<sup>1)</sup> Chapter VI assumed a step function for consumption, but only as a convenient means of testing the 6 year cycle on the trade and futures market sector.

usage (ICUR) and this maximum sale rate (equations 102, 103 ).

The amount of green coffee bought during a year, i.e. imports, is given by the Green-Coffee-Export-Rate (GCER), a variable defined previously in the production sector, and equal to the average between the Desired-Producer-Export-Quantity (DPEXQ) and the Desired-Traders-Import-Quantity (DTIMQ). This type of relation results from our assumptions about the Supplier-Trader price-quantity bargaining decision process. (See BI-19. ). The quantity imported (GCER) does not immediately arrive into the trader's warehouse; a time delay of about three months (DToo) will be required before the purchased coffee is ready to be used as on hand stock. A third order delay simulates this effect (equation 104 ).

$$L \quad TOHSGC.K = TOHSGC.J + DT * (AGCER.JK - PUR.JK) \quad (100)$$

$$L \quad TOOSGC.K = TOOSGC.J + DT * (GCER.JK - AGCER.JK) \quad (101)$$

$$R \quad PUR.KL = \min(TOHSGC.K / DT, ICUR.K) \quad (102)$$

$$A \quad ICUR.K = \text{MODEL INPUT} \quad (103)$$

$$R \quad GCER.KL = \text{defined in production sector (equation 78)}$$

$$R \quad AGCER.KL = \text{DELAY3}(GCER.JK, DToo) \quad (104)$$

$$C \quad DToo = 0.25$$

TOHSGC - Traders on Hand Stocks of Green Coffee (million bags)  
 TOOSGC - Traders on Order Stocks of Green Coffee (million bags)  
 PUR - Processors Usage Rate (million bags/year)  
 ICUR - Indicated Usage Rate (million bags/year) (input to World Coffee Model)



GCER - Green Coffee Export Rate (million bags/year)  
 AGCER - Arrival Rate of Exports) (million bags/year)  
 DTOO - On Order Delay (years)

## 2. Green-Coffee-Required-Imports (GCRI) and Desired-Stock Level (DETS)

Sales tend to deplete stocks. If sales of green coffee were constant throughout the year, and if, in addition, there were no replenishment delays (DTOO) within the coffee distribution channels, the trader would always buy an amount equal to his sales to maintain a certain level of stocks. But sales do change and fluctuate throughout the year, and delays create uncertainty about the arrival of supplies. Hence, a trader will always tend to keep his stocks at a level high enough to cover and protect his business against these and other unpredictable events. A rational replenishment inventory policy is to order an amount equal to the average sales over a certain period of time, and adjust this quantity with whatever is required to restock to the required (desired) level. Thus,

$$\begin{array}{l} \text{Required} \\ \text{Purchases} \\ \text{Per Year} \end{array} = \begin{array}{l} \text{Average Sales} \\ \text{Per Year} \end{array} + \frac{1}{\text{TCT}} \left\{ \begin{array}{l} \text{Desired Stock} \\ \text{Level} \end{array} - \begin{array}{l} \text{Current} \\ \text{Stocks} \end{array} \right\} \quad (a)$$

where TCT, Traders-Correction-Time, is the period of time required to drive the level of stocks to its desired value; it is a parameter established by management, perhaps half a year (TCT = 0.5) to one and a half years at most (TCT  $\simeq$  1.5).

On the average, a value of 0.8 years may provide a good compromise between the two extreme situations (equation 105). Average Sales (Average-Processor-Usage-Rate APUR) is given by equation 106.

Current stocks in expression (a) refer to both on hand and on order stocks of green coffee ( $TSGC = TOHSGC + TOOSGC$ ). Omission of the amount in the pipeline (On Order Stock,  $TOOSGC$ ) from the inventory replenishment policy results in unstable stock behavior with wide oscillations, as described by Forrester [57, Chapter 17] and shortly explained in page 122 of this research (See equation 107).

Finally, the Desired-Traders-Stock (DETS) is then equal to the product of the Average-Processor-Usage-Rate and the desired coverage (the Desired-Traders-Year-Supply DTYS) as depicted by equation 108.

$$A \quad GCRI.K = APUR.K + (DETS.K - TSGC.K) / TCT \quad (105)$$

$$C \quad TCT = 0.8$$

$$A \quad APUR.K = SMOOTH(ICUR.K, TAPP) \quad (106)$$

$$C \quad TAPP = 0.5 \quad (107)$$

$$A \quad DETS.K = DTYS.K * APUR.K \quad (108)$$

APUR - Average Processor Usage Rate  
(million bags/years)  
TAPP - Time to Average Usage Rate (years)  
TSGC - Total Trader Stocks of Green Coffee  
(million bags)  
GCRI - Green Coffee Required Imports  
(million bags/year)  
TCT - Traders Correction Time (years)

DETS - Desired Traders Stock Level  
(million bags)  
DTYS - Desired Traders Year Supply (years)

### 3. Desired-Traders-Year-Supply (DTYS) and Supply-of-Storage-Multipliers (TSOSM and TSHE)

The desired inventory coverage is given in years supply (Desired-Traders-Year-Supply, DTYS). Traders will adjust their desired coverage to low or high years of supply in response to anticipated expectations about price trends in the coffee market, as hypothesized by the theory of Supply of Storage previously described in an earlier chapter. Figure B II-a presents several curves of supply of storage as given by Weymar [45, p 39]. In the absence of a future market, the trader would be unable to carry a portion of his stocks in futures; hence, he will tend to keep  $C_0$  years of coverage. Nevertheless, as the potentialities to use a future market as a hedging device rise, the trader, able to maintain a larger stock of coffee in hedged future contracts, would require less coverage to conduct his business. Hence, desired coverage falls to  $C_1$  and  $C_2$ , while the volume of hedged contracts rise to  $H_1$  and  $H_2$ . Figure BII-1-a shows the traditional way in which literature refers to the supply of storage; Desired Coverage is given as a function of both expected price change and volume of outstanding contracts. Thus,

$$DTYS = \Psi(\Delta P, H) \simeq \Psi_1(\Delta P) \times \Psi_2(H)$$

Equations 109 present the Desired-Traders-Year-Supply as the product

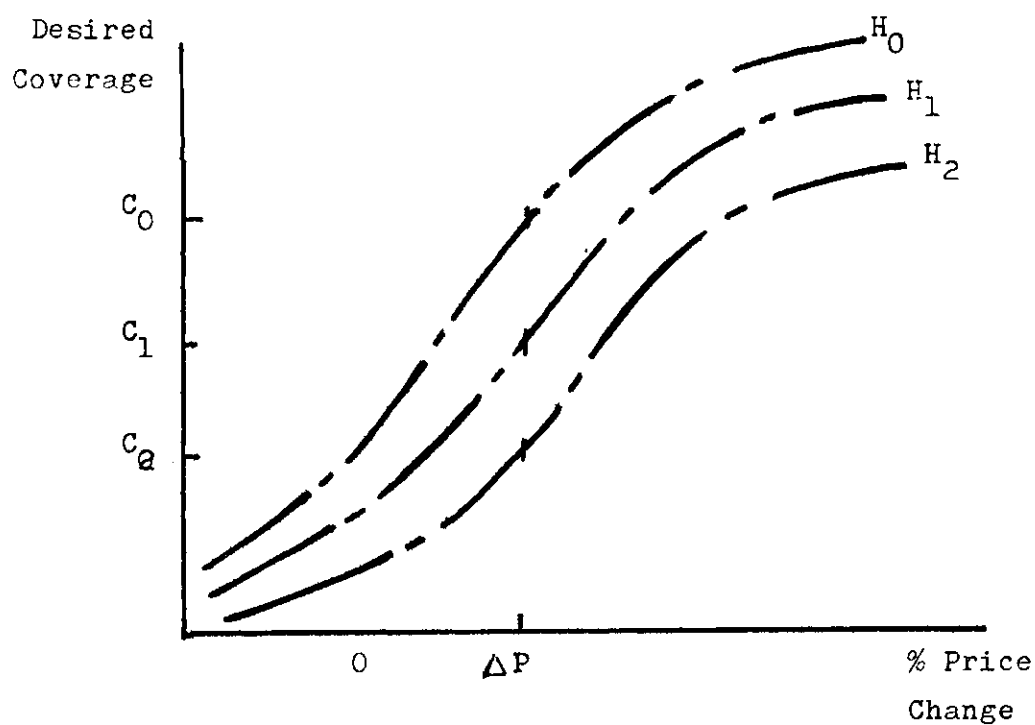
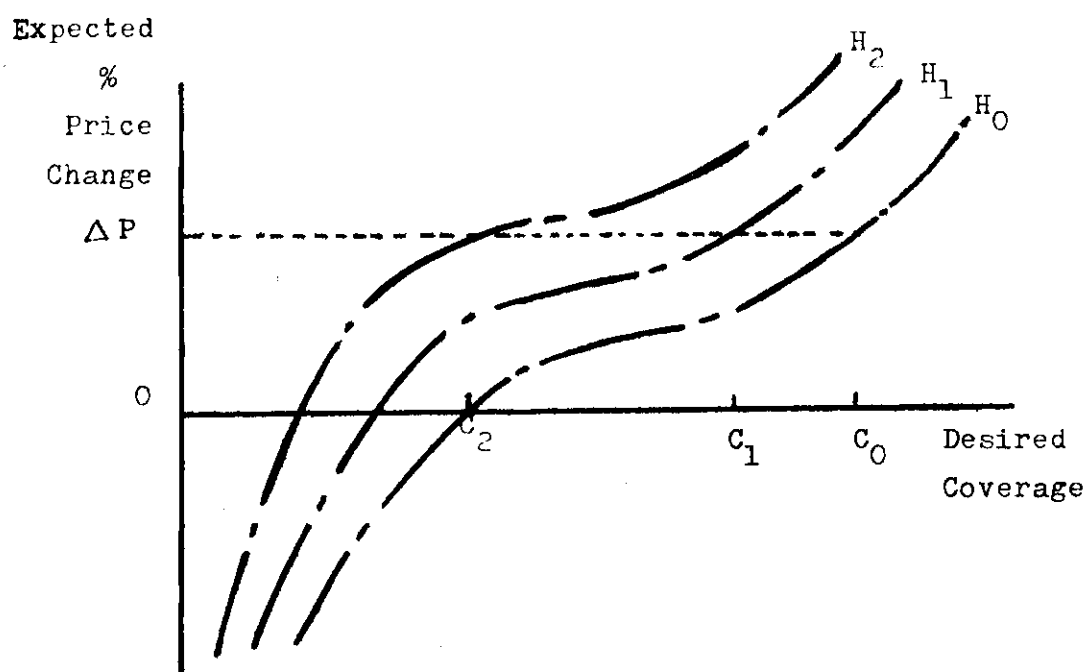


Figure BII-1. Supply of Storage at Different Levels of Hedging.

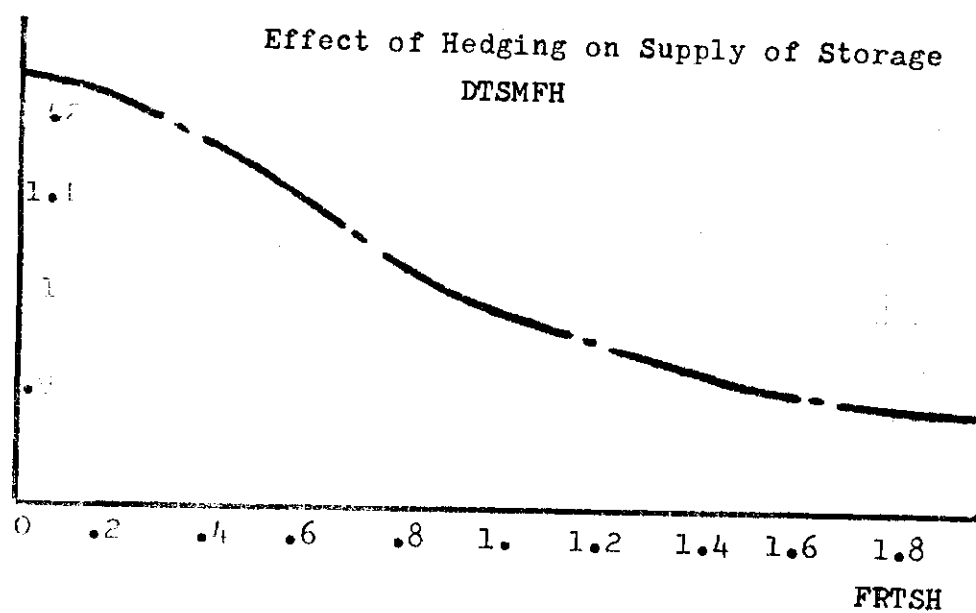
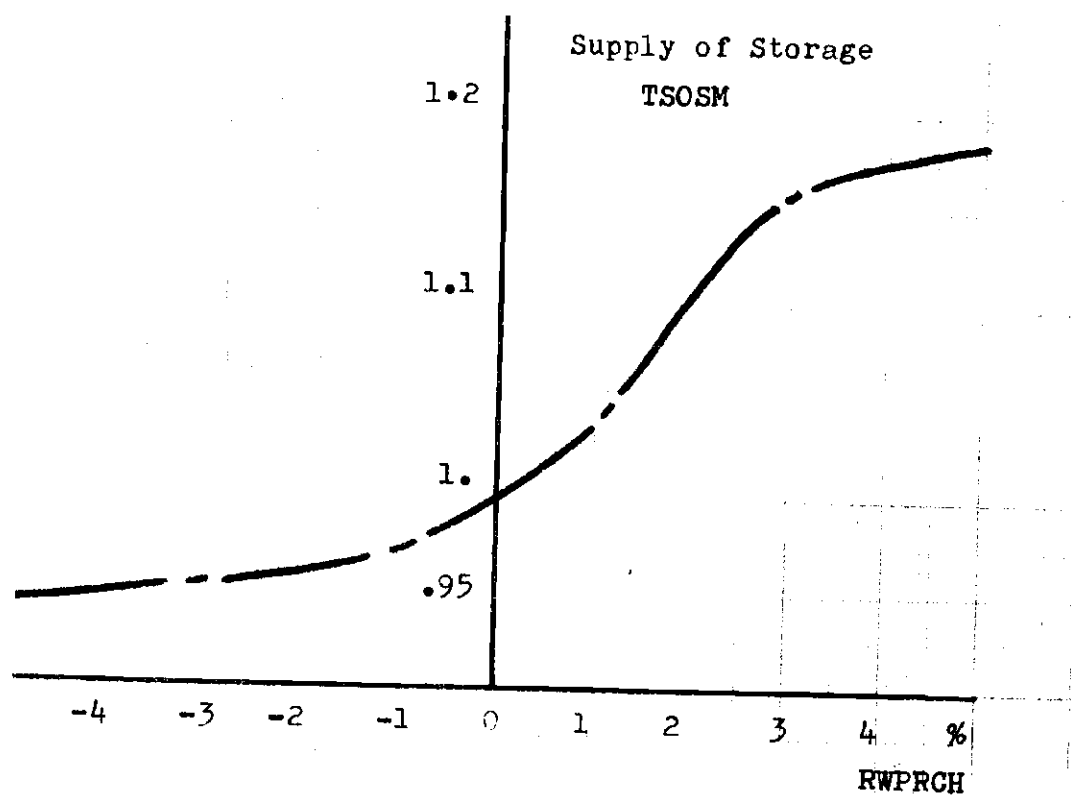


Figure BII-2. Supply of Storage Multipliers.

of a normal coverage in years ( $NDTVS=0.5$ ) and two multipliers, one the Traders-Supply-of-Storage Multiplier ( $TSOSM = \Psi_1(\Delta P)$ ) and a second whose effect is to reduce the coverage when larger volume of stocks are carried in the form of hedged contracts ( $DTSMFH = \Psi_2(H)$ ). The SMOOTH operator in (109) introduces a time delay of half a year in the formation of the Desired-Traders-Years-Supply (DTYS). Equations 110 and 111 describe the two supply-of-storage multipliers as functions of price change (RWPRCH) and fraction of Stocks hedged (FRFSH) respectively. See Figure BII-2.

$$\begin{array}{ll}
 A & DTYSI.K = NDTYS * TSOSM.K * DTSMFH.K \\
 C & NDTYS = 0.5 \\
 A & DTYS.K = SMOOTH(DTYSI.K, TADTYS) \\
 C & TADTYS = 0.5 \\
 A & TSOSM.K = TABHL(1, RWPRCH.K, -0.05, 0.05, 0.01) \\
 T & TSOS = 0.94/0.95/0.96/0.97/0.98/1/1.04/1.12/1.16/1.18/1.19 \quad (110) \\
 A & DTSMFH.K = TABHL(TSHE, FRTSH.K, 0, 2, 0.2) \\
 T & TSHE = 1.25/1.22/1.18/1.12/1.05/1/0.98/0.95/0.92/ \\
 & 0.91/0.90 \quad (111)
 \end{array}$$

DTYSI - Desired Traders Year Supply  
           Indicated (years)  
 NDTYS - Normal Traders Year Supply  
           Indicated (years)  
 DTYS - Desired Traders Year Supply  
           (Years)  
 TRDTYS - Time to Average Desired  
           Year Supply (Years)  
 TSOSM - Traders Supply of Storage Multiplier  
           (dimensionless)

RWPRCH	-	% World Price Change (dimensionless)
DTSMFH	-	Desired Traders Stocks Multiplier from Hedging (dimensionless)
FRTSH	-	Fraction of (Trader) Stocks Hedged (dimensionless)

#### 4. Relative-Aggressiveness-of-Buyers-over-Sellers (RABS) and Average World Futures-Price (AWFPR)

World futures price tends to move together with world spot prices over the long run. Generally, however, futures prices tend to quote below the spot price, although during certain periods of high prices they may quote above it, i. e. the coffee future market has been traditionally an 'inverted' market. How far futures prices quote below or above the spot price depends on the needs of both buyers and sellers. If buyers are more urgent to buy than sellers, futures quoted prices will tend to rise, otherwise they will fall or stay unchanged. In turn, the difference between the intended (desired) purchases and the intended (desired) sales establishes which of the two groups is more urgent to act. When intended purchases rise above intended sales, buyers tend to dominate the market; hence, Dominance-of-Buyers-over-Sellers (DOBS) rises, which creates pressures on the buying side and then higher future-price quotations. On the other hand, when intended sales rise above intended purchases, the market exhibits pressure on the selling side, pressures which tend to depress prices. This effect is depicted in Figure BII-3, where RABS is the Relative-Aggressiveness-of-Buyers-over-Sellers.

The relationship shown in the figure by the subject line is but one, among

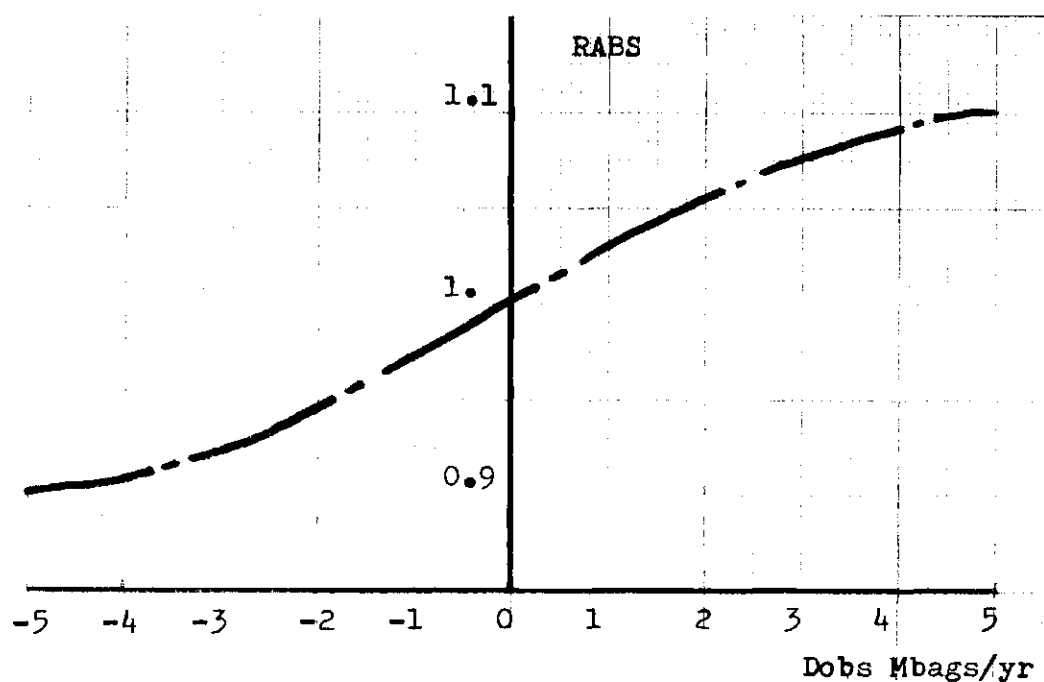


Figure BII-3. Relative Aggressiveness of Buyers over Sellers and  
Future-Price Formation.

several other possibilities. The shape of the relation depends, however, on the way the market responds to excess of buying over selling or vice versa, equation 113.

Equation 112 shows the world future price as the product of the current spot price and two multipliers. The first, the Relative-Aggressiveness-of-Buyers-Over-Sellers (RABS) was already described. The second effect is called Future-Price-Multiplier-from-Selling-Distants over nexts (FPMSD); the nature and functioning of this multiplier is described in the following paragraphs.



The futures coffee market has traditionally been an inverted market; the price of the less distant futures tends to be higher than the price of more distant futures [18]. Gray [13, p. 307, 309] describes the coffee market in the following terms:

...the fitted regression lines show unequivocally that price changes in the distant future tended to be greater, not less, than in the near future.... Spreads have tended to widen more after they have already widened relative to the previous delivery month; and to narrow more after they have narrowed. I infer that spreads have tended to widen owing to the pressure of hedge sales in the distant future. On the assumption that it is the initiative or lack of initiative of selling hedgers that tends to dictate the spread pattern (which widens on price declines and is stable or narrows slightly on price increases), then this tendency of spread movements to continue suggests that the selective hedging of importers is successful. The short hedges, that is to say, tend to cost more when they are worth more. That the hedger does use distant futures is indicated in the fact that the concentration of open interest by delivery months is further removed from the current date in coffee than in other futures markets...

Consider first the behavior of hedgers. Assume  $B_1$  and  $B_2$  are the basis, i.e. spread, at times  $t_1$  and  $t_2$  respectively. The profit or loss rendered by a (short) hedge established at  $t_1$  and lifted at  $t_2$  is given by  $B_1 - B_2$ . When the basis widens on a price decline,  $B_1$  tends to be larger than  $B_2$  (See Figure BII-4). The fact that the price of more distant futures tends to decay faster than the price of less distant futures implies a higher likelihood of a profit hedge when the hedge is established in the more distant futures (when  $B_1 - B_2$  is larger). Therefore, when the basis widens, hedgers are anxious to sell distant futures in preference to next futures.

Spread speculators, on the other hand, will tend to purchase the distant futures offered to keep their long position, as usual (Gray [14], Coffee [18]). Price

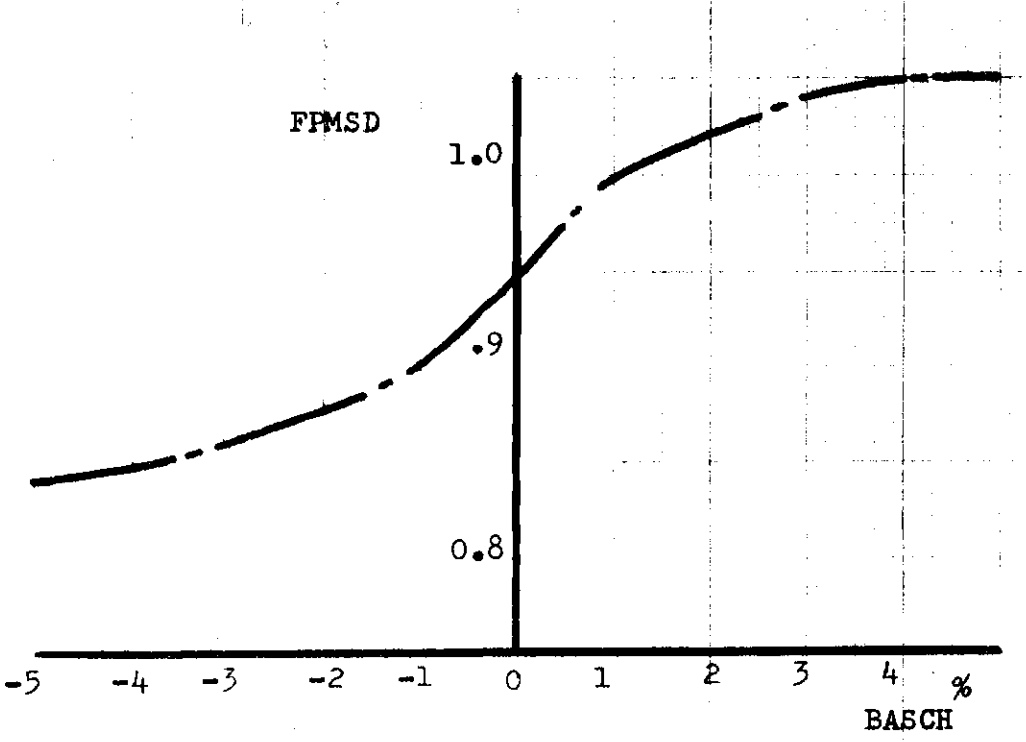


Figure BII-4. Future Price Multiplier from Selling  
Distant over Nexts.

Table BII-1. Rising Prices (Basis Narrowing,  $\Delta B > 0$ )  
Declining Prices (Basis Widening,  $\Delta B < 0$ )

	Desired Position	Probable Outcome	Dominant Force		Note
			Next Futures	Distant Futures	
<u>RISING PRICES:</u>					
<u>Speculators:</u>					
1. On Price	Long	Profit		Buy	The basis narrows. The pressure to buy distants and sell nexts explains why the spread between nexts and di distants narrows.
2. On Basis	Long	Profit		Buy	
<u>Hedgers:</u>	Short	Lose	Sell		
<u>DECLINING PRICES:</u>					
<u>Speculators:</u>					
1. On Price	Short	Profit		Sell	The basis widens. Pressure to sell distants over nexts pushes the spread down, $\Delta\beta < 0$ ; selling pressure due to oversupply pushes price down even more.
2. On Basis	Long	Profit		Buy	
<u>Hedgers:</u>	Short	Even		Sell	

trend speculators, however, will seek to establish a short position in distant, as distant generally fall faster than next futures (they sell at high price and later buy at the lowest price to cancel their commitment). Therefore, when the basis widens ( $\Delta\beta = \beta_2 - \beta_1$  is negative) the market exhibits a net pressure from hedgers and price trend speculators to sell distant futures. (See Table BII-1.) Then when the basis widens, the average futures price tends to fall.

When the basis narrows ( $\Delta\beta > 0$ ) on a price rise the selling pressure on the distant is relieved. In this case, B1 is lower than B2 and there is a likelihood that the hedge results in a loss. Over this period hedgers tend to use the market in a selective manner to minimize their losses. Both types of speculators, on the other hand, tend to buy distant to establish long positions. The two effects of hedgers and speculators combine to create a net buying pressure on the average future price (See Table BII-1 and Figure BII-4).

$$\begin{array}{ll}
 \text{A} & \text{WFPRI.K} = \text{WPRI.K} * \text{RABS.K} * \text{FPMSD.K} \\
 \text{A} & \text{AWFPR.K} = \text{SMOOTH}(\text{WFPRI.K}, \text{TRWPR}) \\
 \text{C} & \text{TAWPR} = 1 \\
 \text{A} & \text{RABS.K} = \text{TABHL}(\text{TABS}, \text{DOBS.K}, -5, 5, 1)
 \end{array}
 \quad \left. \vphantom{\begin{array}{l} \text{A} \\ \text{A} \\ \text{C} \\ \text{A} \end{array}} \right\} \begin{array}{l} (112) \\ \\ \\ (113) \end{array}$$

$$\begin{aligned}
 T \quad & \text{TABS} = 0.9/0.91/0.92/0.95/0.98/1/1.02/1.05/1.07/1.09/1.1 \\
 A \quad & \text{FPMSD.K} = \text{TABHL}(\text{TSDN}, \text{RBASCH.K}, -0.05, 0.05, 0.01) \quad (114) \\
 T \quad & \text{TSDN} = 0.84/0.85/0.86/0.88/0.9/0.95/0.98/1/1.02/1.04/1.05
 \end{aligned}$$

WFPRI	-	World Future Price Indicated (¢/lb)
WPRI	-	World (Spot) Price (¢/lb) (link) defined in Production Sector, eqn.
AWFPR	-	Average Future World Price (¢/lb)
TAWPR	-	Time to Average World Future Price (¢/lb)
RABS	-	Relative Aggressiveness of Buyers over Sellers (dimensionless)
DOBS	-	Dominance of Buyers over Sellers (million bags/yr)
FPMSD	-	Future Price Multiplier from Selling Distant Futures over Nexts (dimensionless)
RBASCH	-	Percent Basis (Spread) change (dimensionless)

## 5. World-Price-Change (WPRCH) and Spot Price-

### Multiplier-from-Future-Price (WPRMFP)

A change in price (spot or future) is the difference between current quoted price and average price; the fractional change in price is the ratio of this difference to average price. Equations 115 show the fractional price change for both spot (WPRCH) and futures price (FPRCH). A new established rate of price change throughout the market place is perceived only after a certain period of time; this is the reason to SMOOTH the two actual price changes in equations 116. More importantly, traders tend to form their expectations about future price movements on the basis of the average rate of price change, that is,

average price trend.<sup>2)</sup>

In general, different markets and different traders may respond differently to a certain rate of price change. While some may overreact to a small price fluctuation, others may wait until a stronger price movement develops. The purpose of equations 117 is to model this response.<sup>3)</sup>

Loop T3 in Chapter VI showed an effect of future-price change on spot world prices. More precisely, loop T3 postulated that expectations about future-price trends have a direct effect on spot price formation. Thus,

$$\begin{aligned} \text{World (Spot) price} &= \text{normal price} \times \Psi(\text{Relative Coffee Availability}) \\ &\times \Phi(\text{average future-price change}). \end{aligned}$$

This equation appears in the Coffee Production sector (Appendix B-I). The function  $\Phi$  is called the World-Price-Multiplier-from-Future-Price (WPRMFP), and is depicted by Figure BII-5 and equation 118. The curbing of the function as future-price-change approaches too high or too low values, reflects the traders' concern that well established coffee price trends, rising or falling too

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<sup>2)</sup> The SMOOTH operator in DYNAMO is exponential smoothing. In this type of average, recent events are given a larger weight than older ones. Commodity analysis seems to confirm the hypothesis that traders form expectations about the future, on the basis of historical smoothing averages (Meadows, DCCM [43, p.25], section on expectations).

<sup>3)</sup> The entire trade and future market sector can be totally omitted from the World Coffee Model by making WPSD, WFPSD in (117) and TCT in equation 105 equal to a very large number. This allows running the simulations on the Production Sector alone.

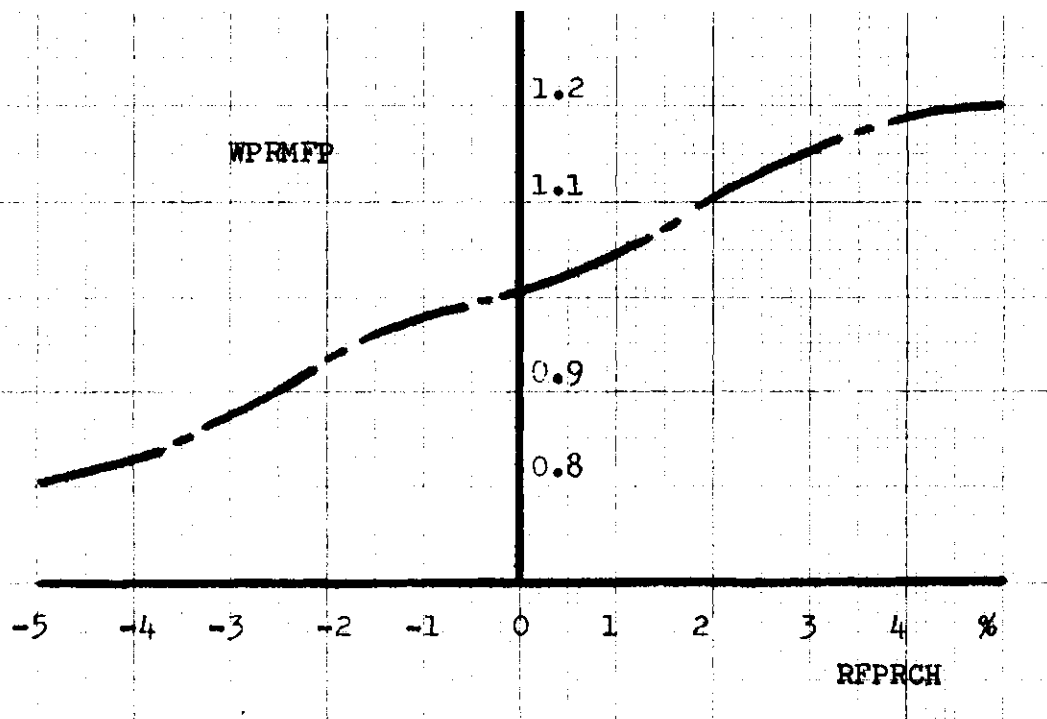


Figure BII-5. Spot Price Multiplier

fast, may soon reverse to follow the characteristic wave pattern.

$$\begin{array}{ll} A & WPRCH.K = (WPRI.K - AWPR.K) / AWPR.K \\ A & FPRCH.K = (WFPRI.K - AWFPR.K) / AWFPR.K \end{array} \quad \left. \vphantom{\begin{array}{l} A \\ A \end{array}} \right\} \quad (115)$$

$$\begin{array}{ll} A & AWPRCH.K = \text{SMOOTH}(WPRCH.K, TAPCH) \\ A & AFPRCH.K = \text{SMOOTH}(FPRCH.K, TAPCH) \end{array} \quad \left. \vphantom{\begin{array}{l} A \\ A \end{array}} \right\} \quad (116)$$

$$C \quad TAPCH = 0.5$$

$$A \quad RWPRCH.K = AWPRCH.K / WPSD$$

$$C \quad WPSD = 7.5 \quad \left. \vphantom{C} \right\} \quad (117)$$

$$A \quad RFPRCH.K = AFPRCH.K / WFPSD$$

$$C \quad WFPSD = 7.5$$

$$\begin{array}{ll} A & WPRMFP.K = \text{TABHL}(TFPR, RFPRCH.K, -0.05, 0.05, 0.01) \\ T & TFPR = 0.8/0.8/0.9/0.95/0.98/1/1.05/1.1/1.15/1.2/1.2 \end{array} \quad \left. \vphantom{\begin{array}{l} A \\ T \end{array}} \right\} \quad (118)$$

WPRCH	-	World (Spot)	} Price Change (dimensionless)
FPRCH	-	World Future	
AWPRCH	-	Average World (Spot)	} Price Change (dimensionless)
AFPRCH	-	Average Future	
TAPCH	-	Time to Average Price Change (Years)	
RWPRCH	-	} Relative Price Change (dimensionless)	
RFPRCH	-		
WPSD	-	} Price Significant Change (dimensionless)	
WFPSD	-		
WPRMFP	-	World Price Multiplier from Future Price (dimensionless). See equation 81 in Production Sector.	

## 6. Open-Interest (OPIN) and Fraction-of- Stocks-Hedged (FRTSH)

Open Interest in the future market is the total number of unliquidated contracts at the end of each period of time. It is also called open commitment. Open Interest at the end of a period  $t$  is equal to the open interest at the end of period



$t - 1$  plus the net variation of commitments during the period. When a trader who is short in the futures market sells a contract, he increases his own open commitment by one contract. If the buyer of the contract is also short, he has reduced by one contract his open commitment. Therefore, total open interest in the market has not changed. If, on the other hand, the buyer of the contract is long (or has no position), he has increased his own long position by one contract. Thus, in this case open interest in the future market rises by two contracts. Figure BII-6 presents the total number of possible combinations; the direction of the arrows shows the direction followed by open interest after the transaction.<sup>4)</sup>

		Buyer		
Seller	Actual Position	Short	Long	N. P
	Short	No Change	↑	↑
	Long	↓	No Change	No Change
	NP	No Change	↑	↑

Figure BII-6. Open Interest Behavior.

Consider the first row of the previous figure. When 'shorts' sell contracts to 'longs' the open interest rises. This is a case in which shorts have sold and longs have bought 'new' contracts. Rising open interest tends to be caused by New-Selling and New-Buying-Rates (NSR and NBR). A similar description holds

<sup>4)</sup> A paper by Beveridge [35] presents readable material about this topic.

for the third row in Figure BII-6.

When 'longs' sell contracts to 'shorts' (second row in the figure), both long and shorts cancel a portion of their commitments. Thus, open interest falls. A long who sells contracts is in fact 'liquidating' a portion of his outstanding contracts; similarly, a short who buys contracts is 'covering' a portion of his outstanding contracts. Then, declining open interest tends to be caused by Long Liquidation and Short Covering Rates (LLR and SHCR). These are the reasons to use plus signs for NSR and NBR, and negative signs for LLR and SHCR in equation 119.

Equation 120 represents the average level of open interest (AOPINS). Recall that the total short position in the market is equal to the total long position and both equal to the open interest. Thus, the average open interest measures the average short position held in futures over a period of time. In turn, the fraction of stocks hedged (FRTSH) indicates the level of protection received by traders when they use the future market as a hedging device. Thus, it can be approximated by the ratio between their average short position (AOPIN) and the total amount of stocks held by the trader (TSGC), equation 121.

$$L \quad OPIN.K = OPIN.J + DT * (NSR.JK - LLR.JK + NBR.JK - SHCR.JK) \quad (119)$$

$$A \quad AOPIN.K = SMOOTH(OPIN.K, TAOPIN) \quad (120)$$

$$C \quad TAOPIN = 0.5$$

$$A \quad FRTSH.K = AOPIN.K / TSGC.K \quad (121)$$

$$N \quad FRTSH = 0.5$$

OPIN	-	Open Interest (million of bags)
NSR	-	New Selling Rate (million bags/yr)
LLR	-	Long Liquidation Rate (million bags/yr)
NBR	-	New Buying Rate (million bags/yr)
SHCR	-	Short Covering Rate (million bags/yr)
AOPIN	-	Average Open Interest (million bags)
TAOPIN	-	Time to Average Open Interest (years)
FRTSH	-	Fraction of Stocks Hedged (fraction)

## 7. New-Selling-Rate (NSR) and Short-Covering-Rate (SHCR)

New-Selling-Rate and Short-Covering-Rate are actions taken by traders whose position is short, as described in the previous section. Depending upon the outlook of the coffee economy some traders and speculators will be willing to establish larger or lower short positions. If the desired short position is larger than the current open commitment, traders will be induced to sell new contracts to increase their interest. On the other hand, if the desired short position is lower than the current commitment, traders will buy contracts to cancel out a portion of their interest. In the first case, New-Selling-Rate was high, in the second, short covering rates tend to be large, equations 122 and 123. Generally, not all of the Indicated-New-Sale-Rate (INSR) or Indicated-Short-Covering-Rate (ISHCR) can be purchased or sold during each period of time. If traders wish to sell too many contracts and just happen that there are few buyers, the actual net sales rate will tend to be lower than initially. For a similar reason, not all of the indicated short covering rate (ISHCR) will be sold. Hence, equation 124 gives the New-Selling-Rate (NSR) and the Short-Covering-Rate (SHCR) as the product between the two indicated values (INSR and ISHCR) and fractions lower (or equal) 1, respectively. These two fractions (FSM and

FPM) vary through time, depending upon the volume of trade in the market. (See Section 9.)

$$A \quad PRSH.K = (ADVSH.K - OPIN.K) / SHCT \quad (122)$$

$$C \quad SHCT = 0.5$$

$$A \quad INSR.K = \text{MAX}(PRSH.K, 0) \quad \left. \vphantom{\begin{matrix} A \\ A \end{matrix}} \right\} (123)$$

$$A \quad ISHCR.K = \text{MAX}(-PRSH.K, 0)$$

$$R \quad NSR.K \bar{L} = INSR.K * FSM.K \quad \left. \vphantom{\begin{matrix} A \\ A \end{matrix}} \right\} (124)$$

$$R \quad SHCR.KL = ISHCR.K * FPM.K$$

	ADUSH	-	Desired Short Position (million bags)
	OPIN	-	Open Interest (million bags)
	PRSH	-	Pressure to Establish Short Position (million bags/yr.)
	SHCT	-	Shorts Correction Time (years)
	INSR	-	Indicated New Selling Rate (million bags/yr)
	ISHCR	-	Indicated Short Covering Rate (million bags/yr)
*	NSR	-	New Selling Rate (million bags/yr)
*	SHCR	-	Short Covering Rate (million bags/yr)
	FSM	-	Fraction Possible of Sales to Make (fraction)
	FPM	-	Fraction Possible of Purchases to Make (fraction)

#### 8. New-Buying-Rate (NBR) and Long-Liquidation-Rate (LLR)

Equations 125, 126 and 127 are counterparts of equations 122, 123, and 124 respectively. These equations were described in the previous section. Repetition of a similar explanation is omitted here.

$$A \quad PRLO.K = (ADVLO.K - OPIN.K) / LOCT \quad (125)$$

$$C \quad LOCT = 0.5$$

$$A \quad INBR.K = \text{MAX}(PRLO.K, 0) \quad \left. \vphantom{\begin{matrix} A \\ A \end{matrix}} \right\} (126)$$

$$A \quad ILLR.K = \text{MAX}(-PRLO.K, 0)$$

$$\begin{array}{ll}
 R & \text{NBR.KL} = \text{INBR.K} * \text{FPM.K} \\
 R & \text{LLR.KL} = \text{ILLR.K} * \text{FSM.K}
 \end{array}
 \quad \left. \vphantom{\begin{array}{l} R \\ R \end{array}} \right\} \quad (127)$$

PRLO	- Pressure to Establish Long Position (million bags/yr)
LOCT	- Longs Correction Time (years)
INBR	- Indicated New Buying Rate (million bags/yr)
ILLR	- Indicated Long Liquidation Rate (million bags/yr)
NBR	- New Buying Rate (million bags/yr)
LLR	- Long Liquidation Rate (million bags/yr)
FSM	- Fraction Possible of Sales Made (fraction)
FPM	- Fraction Possible of Purchases Made (fraction)

#### 9. Volume-of-Trade (IVOT) and Dominance-of-Buyers- Over-Sellers (DOBS)

The total amount of indicated purchases in the futures market is equal to the sum of indicated purchases by both longs and shorts. In other words, it is the addition of the Indicated-New-Buying-Rate and the Indicated-Short-Covering-Rate (INBR + ISHCR). Similarly, total indicated sales in the future market is then, the addition of Indicated-New-Sales-Rate and Indicated-Long-Liquidation-Rate (INSR + ILLR). The SMOOTH operator in equation 128 gives the average indicated purchases and sales respectively, over a period of time.

Volume of trade (IVOT) is thus the minimum between the Total-Indicated-Purchases (TIPEM) and the Total-Indicated-Sales (TISFM), as given by equation 129. The Fraction of Purchases and sales actually made in the market (FPM and FSM) are then given by the ratio between volume of trade and the indicated purchases and sales, respectively, equation 130.<sup>5)</sup>

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<sup>5)</sup> In the computer printout of the model equations, the denominators of

Equation 131 gives the excess or shortage of indicated purchases with respect to indicated sales. If there exist an excess of the first amount over the second, buyers tend to dominate the market, otherwise sellers will dominate it. DOBS is then, Dominance-Of-Buyers-Over-Sellers. This variable is used to establish price in the future market (See Figure BII-3).

$$\begin{array}{ll}
 \text{A} & \text{TIPFM.K} = \text{SMOOTH}(\text{INBR.K} + \text{ISHCR.K}, 0.5) \\
 \text{A} & \text{TISFM.K} = \text{SMOOTH}(\text{INSR.K} + \text{ILLR.K}, 0.5) \\
 \text{A} & \text{IVOT.K} = \text{MIN}(\text{TISFM.K}, \text{TIPFM.K}) \\
 \text{A} & \text{FPM.K} = \text{IVOT.K} / \text{TIPFM.K} \\
 \text{A} & \text{FSM.K} = \text{IVOT.K} / \text{TISFM.K} \\
 \text{A} & \text{DOBS.K} = (\text{TIPFM.K} - \text{TISFM.K}) / \text{BSSD} \\
 \text{C} & \text{BSSD} = 1
 \end{array}
 \quad \left. \begin{array}{l} \\ \\ \\ \\ \end{array} \right\} \begin{array}{l} (128) \\ \\ \\ (130) \\ (131) \end{array}$$

TIPFM	- Total Indicated Purchases in the Future Market (million bags/yr)
TISFM	- Total Indicated Sales in the Future Market (million bags/yr)
IVOT	- Indicated Volume of Trade (million bags/yr)
FPM	- Fraction of Purchases Made (Fraction)
FSM	- Fraction of Sales Made
DOBS	- Dominance of Buyers over Sellers (million bags/yr)

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equations 130 appear as  $(\text{TIPFM} + 0.001)$  and  $(\text{TISFM} + 0.001)$  respectively. This was done to avoid division by zero when performing runs to test the sensitivity of certain parameters. Specifically, when one increases to high values, the level of quota controls, speculation tends to disappear, and then hedging too. Thus, intended purchases and sales both approach zero.

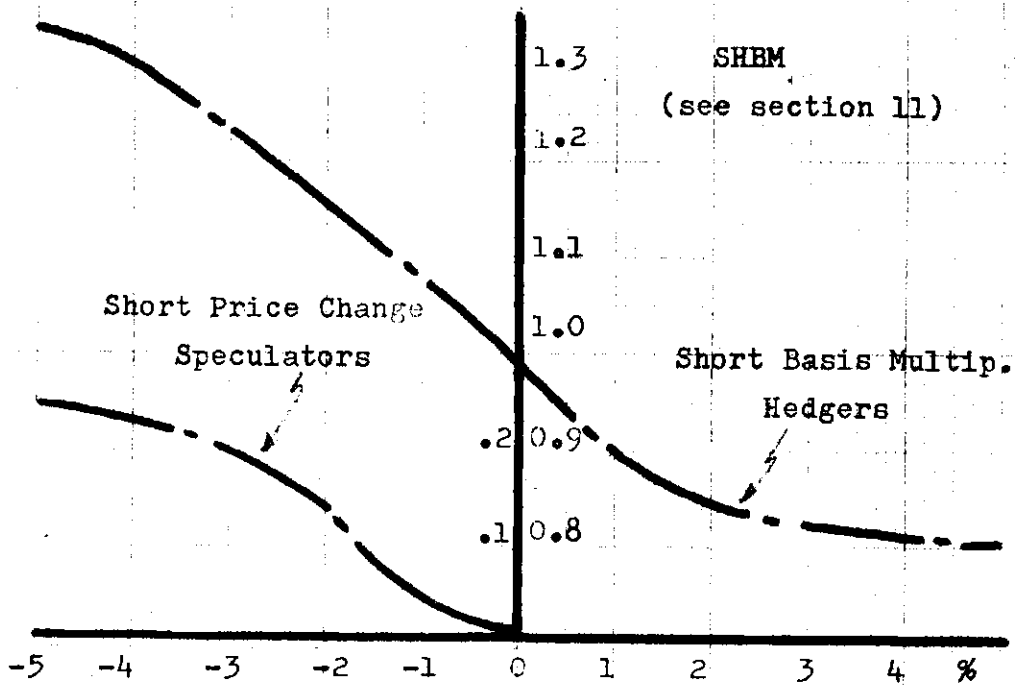


Figure BII-7. Desired Short Position.

BSSD - Buyers-Sellers Significant Difference  
(million bags/yr)

#### 10. (BASIS) and Expected Basis Change (ABASCH)

The indicated basis is the difference between the World-Future-Price (WFPRI) and the World-Price (WPRI). The current change in basis is the difference between the indicated basis and the average basis (BASIS); a fractional basis change (BASCH) is given by the ratio between the above difference and the average basis (BASIS), equations 132 and 133.

Hedgers and Spread Speculators base their decisions to increase or decrease short positions on expectations about the direction of future movements in the basis, that is, the expected change in basis. Some traders will tend to fore-

cast a possible basis change, higher than the most recent average change in basis; others, lower. On the aggregate, traders would expect the basis to change at about a rate equal to the most recent rate given by the Average-Basis-Change (ABASCH), equation 134. Note the initial value given to the basis change (BASCH=0). Initially, when the system is at rest, both spot and future prices stay constant, and thus, the basis does not change.

Equation 135 describes the Relative-Expected-Basis-Change (RBASCH) as a ratio between the expected basis change and a parameter, the Basis-Significant-Difference (BASD). This equation together with the parameter, were introduced into the model to test the sensitivity of the model to different fractional changes in basis.

$$\begin{array}{ll} \text{A} & \text{BASISI.K} = \text{WFPRI.K} - \text{WPRI.K} \\ \text{A} & \text{BASIS.K} = \text{SMOOTH}(\text{BASISI.K}, \text{TABAS}) \end{array} \quad \left. \vphantom{\begin{array}{l} \text{A} \\ \text{A} \end{array}} \right\} \quad (132)$$

$$\text{C} \quad \text{TABAS} = 0.25$$

$$\text{A} \quad \text{BASCH.K} = (\text{BASISI.K} - \text{BASIS.K}) / \text{BASIS.K} \quad (133)$$

$$\text{A} \quad \text{ABASCH.K} = \text{SMOOTH}(\text{BASCH.K}, \text{TPBCH})$$

$$\text{C} \quad \text{TPBCH} = 0.25 \quad \left. \vphantom{\text{C}} \right\} \quad (134)$$

$$\text{N} \quad \text{BASCH} = 0$$

$$\text{A} \quad \text{RBASCH.K} = \text{ABASCH.K} / \text{BASD} \quad (135)$$

$$\text{C} \quad \text{BASD} = 2$$



BASISI	-	Basis (Spread) Indicated (¢/lb)
BASIS	-	Basis (Spread) (C/lb)
TABAS	-	Time to Average Basis (yrs)
BASCH	-	Basis Fractional Change (fraction)
ABASCH	-	Average Basis Change (fraction)
TPBCH	-	Time to Perceive Basis Change (years)
RBASCH	-	Relative Basis Change (fraction)
BASD	-	Basis Significant Difference (¢/lb)

#### 11. Desired-Volume-of-Short-Position (ADVSH)

In the futures market hedgers generally take a short position. Chapter VI of this research described the hedgers' desired short position as a function of the current level of physical stocks held and the trader's expectations about future changes in the basis. Thus,

$$\text{Hedgers' desired Short Position} = \text{Stocks} \times \Phi_{sh} \text{ (Average Basis Change)} \quad (a)$$

The function  $\Phi_{sh}$  is given by equation 136, where SHBM is the Short-Basis-Multiplier, a multiplier which adjusts the target short position above or below a normal value. Under normal conditions, with very low fluctuations in the basis, a trader will tend to hedge a fraction of his stocks, say 50%. (NFRSH = 0.5.) Figure BII-7 depicts the Short-Basis-Multiplier (SHBM) as a function of the expected basis change. As explained in Chapter VI, a positive basis change occurs in the coffee futures market when prices are rising, that is, when the basis narrows. Furthermore, a hedger who routinely maintains a short position in the coffee market tends to lose money in his transactions; the amount lost tends to grow with higher rates of change in the basis [14]. Therefore, when the basis narrows, traders will tend to hedge a lower fraction of stocks

in view of the diminished protection rendered by the futures market. On the other hand, as prices fall, the basis (in the case of coffee) tends to widen, and a hedger who maintains a short position tends to reduce his losses, hedging a larger fraction of his physical stocks. The Short-Basis-Multiplier (SHBM) tends toward a limit as expected basis change approaches an extreme high or low value. Consider first a situation in which the basis is widening too fast (negative basis change). In this case, the market tends to offer the best protection to the hedger, in which case he may hedge at most 100% of his stocks (SHBM=2). Nevertheless, not all of the traders use the futures market, and those who use it, tend to be less anxious to maintain a short position when prices are falling very fast. This explains the gradual saturation of the Short-Basis-Multiplier at the lowest and negative change in basis (SHBM=1.35) is equivalent to hedge about 67.5% of the total traders' stocks).

On the other hand, when the expected change in basis is large and positive, traders will always tend to keep at least a portion of their stocks in hedged future contracts (SHBM = 0.8, ~ 40% of their stocks) as protection against adverse price movements.

As prices fall, professional price-trend speculators will also tend to establish a short position; it has been assumed to depend on both the total desired level of long speculation in the coffee market (the level of amateur speculators who normally hold a long position), and the speed at which prices

fall. Furthermore, the volume of desired short speculative position tends to decrease as stronger quota controls are enforced over the spot market.

Therefore,

Speculators' Desired Short Position = Desired Speculative Long Position

$$\times \Phi_{ss} \text{ (expected price change) } \times \text{Effect of Quota Controls} \quad (b)$$

Function  $\Phi_{ss}$  is the broken line shown in Figure BII-7; it is called Short-Price-Multiplier (SHPM) in equation 137. Equation 138 presents the total desired short position (DVSH) as the addition of two terms of the hedgers' and speculators' desired short positions respectively (expressions (a) and (b)).

Hedgers' and speculators' expectations about price trends and basis change do not immediately produce a variation in the traders' short target. Under a sudden fluctuation in prices or basis, traders will tend to adjust their new target position gradually, giving time to cancel out established commitments in case their initially formed expectations turn out to be false. Therefore, the current desired short position at the futures market (ADVSH) can be best represented by the SMOOTH operator in equation 139.

$$A \quad SHBM.K = TABHL(TSHB, RBASCH.K, -0.05, 0.05, 0.01) \quad (136)$$

$$T \quad TSHB = 1.35/1.3/1.2/1.15/1.1/1/0.9/0.85/0.82/0.81/0.8$$

$$A \quad SHPM.K = TABHL(TSHP, RFPRCH.K, -0.05, 0, 0.01) \quad (137)$$

$$T \quad TSHP = 0.25/0.23/0.20/0.15/0.05/0$$

$$A \quad DVSH.K = TSGC.K * NFRSH * SHBM.K + ADVLO.K * SHPM.K \\ * SPECA.K \quad (138)$$

C     NFRSH=0.5

A     ADVSH. K=SMOOTH(DVSH. K, TASHP) (139)

C     TASHP=0.5

N     DUSH=OPIN

SHBM	-	Shorts Basis Multiplier (dimensionless)
SHPM	-	Shorts Price Change Multiplier (dimensionless)
DVSH	-	Desired Volume of Shorts (million bags)
TSGC	-	Trader Stocks of Green Coffee (million bags)
NFRSH	-	Normal Fraction of Stocks Hedged (fraction)
ADVLO	-	Desired Volume of Longs (Average) (million bags)
SPECA	-	Market Speculative Attraction (fraction)
ADVSH	-	Desired Volume of Shorts (Average) (million bags)
TASHP	-	Time to Average Desired Volume of Shorts (years)
OPIN	-	Open Interest (initial value)(million bags)

## 12. Desired-Volume-of-Long-Position (ADVLO)

Figure BII-8 exhibits two multipliers to adjust the desired long position speculators at the future coffee market. The Long-Basis-Multiplier (LOBM) is given by the solid line in the figure, and displays the effect of expected basis movements on spread speculators. As it was explained in Chapter VI, these speculators normally want to maintain a long position, a position which tends to rise when the basis widens and to decay as the basis narrows (Gray [14]).

The broken line in the same figure shows the Long-Price-Multiplier (LOPM). This function describes the behavior of price-trend speculators when they want to establish a long position as prices rise, equation 141; the lower portion of

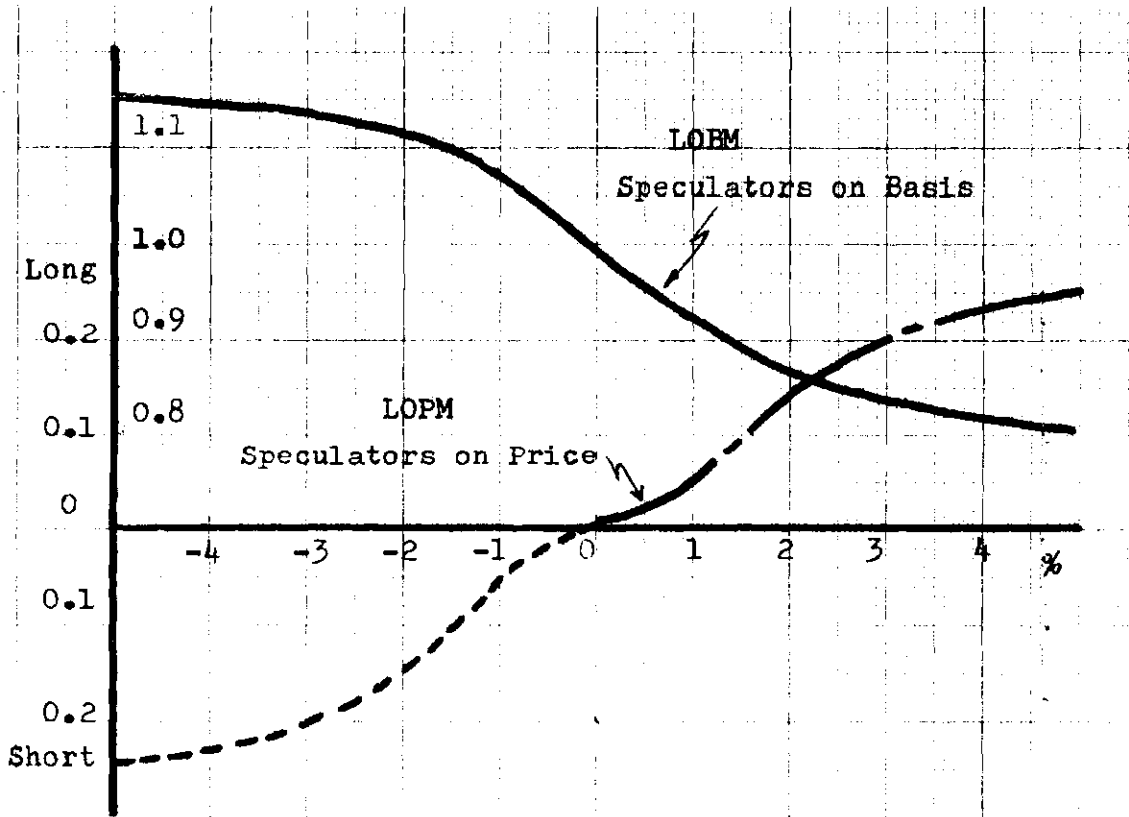


Figure B-II 8  
Desired Long Position by Speculators

the price multiplier represents the Short-Price-Multiplier (SHPM) described in the previous section.

Both price and basis multipliers gradually saturate at the two extremes of the diagram. Consider the broken line first. When prices tend to rise or fall, more traders are attracted toward the coffee market; new traders normally mean a wider differential between the maximal and the minimal daily quoted price.<sup>6)</sup> This in turn, implies rapid and wide short-term price fluctuations, which means that speculators would have to absorb a higher level of risk. Therefore, if prices rise or fall too fast, short-term price fluctuations will tend to become too wild and rampant, a fact which acts as a deterrent to some speculators, who will seek profits in less volatile markets. This is the reason to postulate the two speculators' multipliers as having a shape which saturates at extreme values of price change. A similar explanation could be given to describe the shape of the Longs-Basis-Multiplier (LOBM). This is omitted here.

Equations 142 and 143 describe the desired volume of long position in the future market as the product of desired short position (ADVSH),<sup>7)</sup> the addition of the two long multipliers (LOBM + LOPM) and a third element (SPECa,

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<sup>6)</sup> Charts on future coffee price at the New York Coffee and Sugar exchange show wider short-term price fluctuations when prices rise or fall too fast (Commodity Year Book [2]).

<sup>7)</sup> Equation 142 suggests a rise in the speculative long position as traders tend

Speculators-Attraction) which depends on the level at which price regulations and quota export controls dominate the spot market. This variable is defined by equation 144. A rise in the quota fraction tends to allow exports to flow more freely into the spot market; this in turn attracts a higher number of speculators toward the future coffee market.

$$A \quad LOBM.K = TABHL(TLOB, RBASCH.K, -0.05, 0.05, 0.01) \quad (140)$$

$$T \quad TLOB = 1.15 / 1.14 / 1.13 / 1.12 / 1.08 / 1 / 0.92 / 0.87 / 0.84 / 0.82 / 0.8$$

$$A \quad LOPM.K = TABHL(TLOP, RFPRCH.K, 0, 0.05, 0.01) \quad (141)$$

$$T \quad TLOP = 0 / 0.05 / 0.15 / 0.20 / 0.23 / 0.25$$

$$A \quad DVLO.K = ADUSH.K * (LOBM.K + LOPM.K) * SPECA.K \quad (142)$$

$$A \quad ADVLO.K = SMOOTH(DVLO.K, THLOP) \quad (143)$$

$$C \quad TALOP = 0.25$$

$$A \quad SPECA.K = NSPECA * QUOTA.K \quad (144)$$

$$C \quad NSPECA = 1$$

$$A \quad QUOTA.K = \text{Market export quota controls (defined in Chapter IX)}$$

LOBM	-	Longs Basis Multiplier (dimensionless)
LOPM	-	Longs Price Change Multiplier (dimensionless)
DVLO	-	Desired Volume of Longs (million bags)
ADVLO	-	Desired Volume of Longs (Average)(million bags)
TALOP	-	Time to Average Desired Volume of Longs (years)

---

to increase their short position. Equation 138 on the other hand, assumed the converse. The two equations taken together postulate, in fact, that both hedging and speculation support each other in the commodity future market. See Working [46, 47], Gray [14].

AVVSH	-	Desired Volume of Shorts (million bags)
SPECA	-	Market Speculation Attraction (fraction)
NSPECA	-	Normal Market Speculation Attraction (fraction)
QUOTA	-	Market Export Quota Controls (dimensionless)

### 13. Input to the World Coffee Dynamic Model:

#### Coffee-Usage-Rate (ICUR)

The listing of equations at the end of the Appendix describes annual usage of coffee (ICUR) with exponential growth. The printouts exhibited in the Production Sector and in Chapter VII use this type of function as an input to the World Coffee Model. In those printouts ICUR is plotted with the letter U. The values produced by the exponential function are close to the actual consumption figures, as the reader may confirm it by visual comparison of data with simulated output.

The equations used to generate this type of input appear at the end of the listing of equations, and under the name INPUT. The name of the variables are as follows:

FCPOP	Foreign Countries Adult Population (men)
FPGR	Foreign (Adult) Population Growth Rate (men/year)
GCUPC	Equivalent Green Coffee Usage per Capita (million of bags/ men-year) (an exponential function)
ICUR	Indicated Coffee Usage Rate in Green Coffee Equivalent (million bags/year)

Thus,

$$ICUR.K = FCPPOP.K * GCUPC.K \quad (145)$$



To test the performance of the Coffee Trade and Future Market in Chapter VI, equation 145 was substituted by a STEP function. In that chapter, simulated plots also show the letter U to indicate ICUR. The variable FROST at the end of the listing of equations was used to simulate the effects of adverse weather.

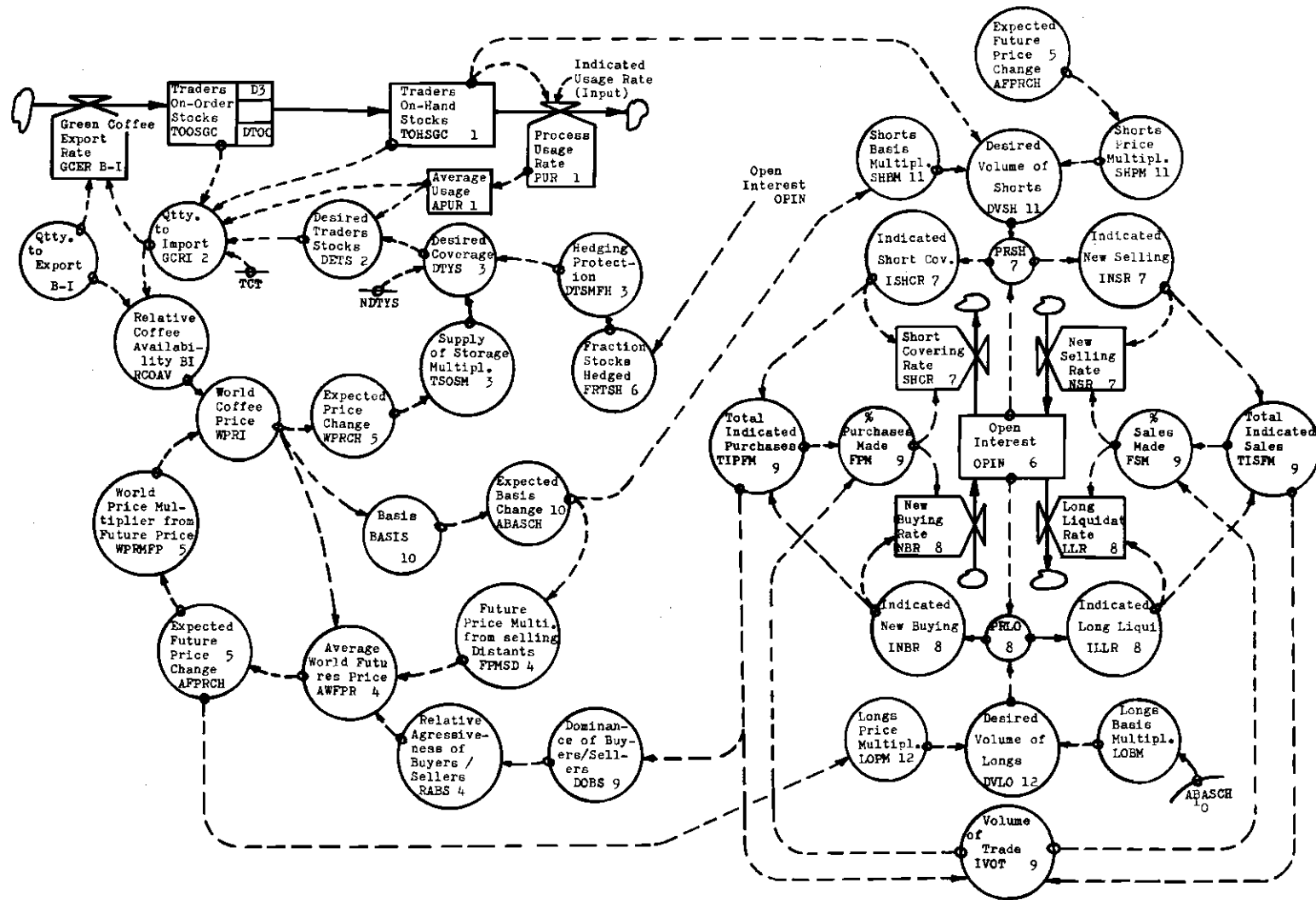


Figure BII-9. Trade Sector DYNAMO Model.

NOTE \*\*\*WORLD COFFEE DYNAMIC MODEL\*\*\*

NOTE

NOTE \*\*\*PRODUCTION SECTOR\*\*\*

NOTE

NOTE LABOR SECTOR

NOTE

L ALAEF.K=ALAEF.J+DT\*(NGALF.JK-MTUC.JK)

N ALAEF=ALAEF1

C ALAEF1=356

L ULAEF.K=ULAEF.J+DT\*(TLC.JK+NGULF.JK)

N ULAEF=ALAEF\*(1+FR-NFLR-FCSGC/NCEI)/ALPLL

N ULAEF=MAX(ULAEO,C)

A TLAEF.K=ALAEF.K+ULAEF.K

R NGULF.K=ALAEF.K\*PYGAL\*GROWTH.K

C PYGAL=0.03

R NGULF.K=ULAEF.K\*PYGUL\*GROWTH.K

C PYGUL=0.02

R MTUC.K=ALAEF.K\*PYM\*ATUC.K\*GROWTH.K

C PYM=0.01

A GSWTE.K=EFIFGE(1,C,TIME,K,JRPP)

C TRPF=3355

A PRCLN.K=ACFN.K\*AFRR.K\*IEE

A TEMCL.K=(LAND.K+LABF.K)\*LUPFA\*(1-ABFT.K)

A EMCL.K=MIN(TEMCL.K,AVCL.K)

C LUPFA=0.20

A INFLL.K=EMCL.K/EMCL.K

A MINFL.K=INFLL.K\*MINFL

N MINFL=INFLL

A ARIFLU.K=SMCOT\*(MINFLU.K,TFIC)

N ARIFLU=1

C TFIC=1

A ATOC.K=IEHL(TAIC,ARIFLU.K,0.8,1.2,0.05)

T TAIC=0.4/0.6/0.8/0.9/1.1/1.2/1.4/1.6

A AINCH.K=(INFLLU.K-ARIFLU.K)/ARIFLU.K

A AINCH.K=SMCOT\*(AINCH.K,1)

N AINCH=0

A ACICHM.K=TAHHL(TATH,AINCH.K,-0.05,0.05,0.01)

T TATH=0.8/1.0/1.2/1.4/1.6/1.8/2.0/2.2/2.4/2.6/2.8/3.0/3.2/3.4/3.6/3.8/4.0/4.2/4.4/4.6/4.8/5.0/5.2/5.4/5.6/5.8/6.0/6.2/6.4/6.6/6.8/7.0/7.2/7.4/7.6/7.8/8.0/8.2/8.4/8.6/8.8/9.0/9.2/9.4/9.6/9.8/10.0/10.2/10.4/10.6/10.8/11.0/11.2/11.4/11.6/11.8/12.0/12.2/12.4/12.6/12.8/13.0/13.2/13.4/13.6/13.8/14.0/14.2/14.4/14.6/14.8/15.0/15.2/15.4/15.6/15.8/16.0/16.2/16.4/16.6/16.8/17.0/17.2/17.4/17.6/17.8/18.0/18.2/18.4/18.6/18.8/19.0/19.2/19.4/19.6/19.8/20.0/20.2/20.4/20.6/20.8/21.0/21.2/21.4/21.6/21.8/22.0/22.2/22.4/22.6/22.8/23.0/23.2/23.4/23.6/23.8/24.0/24.2/24.4/24.6/24.8/25.0/25.2/25.4/25.6/25.8/26.0/26.2/26.4/26.6/26.8/27.0/27.2/27.4/27.6/27.8/28.0/28.2/28.4/28.6/28.8/29.0/29.2/29.4/29.6/29.8/30.0/30.2/30.4/30.6/30.8/31.0/31.2/31.4/31.6/31.8/32.0/32.2/32.4/32.6/32.8/33.0/33.2/33.4/33.6/33.8/34.0/34.2/34.4/34.6/34.8/35.0/35.2/35.4/35.6/35.8/36.0/36.2/36.4/36.6/36.8/37.0/37.2/37.4/37.6/37.8/38.0/38.2/38.4/38.6/38.8/39.0/39.2/39.4/39.6/39.8/40.0/40.2/40.4/40.6/40.8/41.0/41.2/41.4/41.6/41.8/42.0/42.2/42.4/42.6/42.8/43.0/43.2/43.4/43.6/43.8/44.0/44.2/44.4/44.6/44.8/45.0/45.2/45.4/45.6/45.8/46.0/46.2/46.4/46.6/46.8/47.0/47.2/47.4/47.6/47.8/48.0/48.2/48.4/48.6/48.8/49.0/49.2/49.4/49.6/49.8/50.0/50.2/50.4/50.6/50.8/51.0/51.2/51.4/51.6/51.8/52.0/52.2/52.4/52.6/52.8/53.0/53.2/53.4/53.6/53.8/54.0/54.2/54.4/54.6/54.8/55.0/55.2/55.4/55.6/55.8/56.0/56.2/56.4/56.6/56.8/57.0/57.2/57.4/57.6/57.8/58.0/58.2/58.4/58.6/58.8/59.0/59.2/59.4/59.6/59.8/60.0/60.2/60.4/60.6/60.8/61.0/61.2/61.4/61.6/61.8/62.0/62.2/62.4/62.6/62.8/63.0/63.2/63.4/63.6/63.8/64.0/64.2/64.4/64.6/64.8/65.0/65.2/65.4/65.6/65.8/66.0/66.2/66.4/66.6/66.8/67.0/67.2/67.4/67.6/67.8/68.0/68.2/68.4/68.6/68.8/69.0/69.2/69.4/69.6/69.8/70.0/70.2/70.4/70.6/70.8/71.0/71.2/71.4/71.6/71.8/72.0/72.2/72.4/72.6/72.8/73.0/73.2/73.4/73.6/73.8/74.0/74.2/74.4/74.6/74.8/75.0/75.2/75.4/75.6/75.8/76.0/76.2/76.4/76.6/76.8/77.0/77.2/77.4/77.6/77.8/78.0/78.2/78.4/78.6/78.8/79.0/79.2/79.4/79.6/79.8/80.0/80.2/80.4/80.6/80.8/81.0/81.2/81.4/81.6/81.8/82.0/82.2/82.4/82.6/82.8/83.0/83.2/83.4/83.6/83.8/84.0/84.2/84.4/84.6/84.8/85.0/85.2/85.4/85.6/85.8/86.0/86.2/86.4/86.6/86.8/87.0/87.2/87.4/87.6/87.8/88.0/88.2/88.4/88.6/88.8/89.0/89.2/89.4/89.6/89.8/90.0/90.2/90.4/90.6/90.8/91.0/91.2/91.4/91.6/91.8/92.0/92.2/92.4/92.6/92.8/93.0/93.2/93.4/93.6/93.8/94.0/94.2/94.4/94.6/94.8/95.0/95.2/95.4/95.6/95.8/96.0/96.2/96.4/96.6/96.8/97.0/97.2/97.4/97.6/97.8/98.0/98.2/98.4/98.6/98.8/99.0/99.2/99.4/99.6/99.8/100.0/100.2/100.4/100.6/100.8/101.0/101.2/101.4/101.6/101.8/102.0/102.2/102.4/102.6/102.8/103.0/103.2/103.4/103.6/103.8/104.0/104.2/104.4/104.6/104.8/105.0/105.2/105.4/105.6/105.8/106.0/106.2/106.4/106.6/106.8/107.0/107.2/107.4/107.6/107.8/108.0/108.2/108.4/108.6/108.8/109.0/109.2/109.4/109.6/109.8/110.0/110.2/110.4/110.6/110.8/111.0/111.2/111.4/111.6/111.8/112.0/112.2/112.4/112.6/112.8/113.0/113.2/113.4/113.6/113.8/114.0/114.2/114.4/114.6/114.8/115.0/115.2/115.4/115.6/115.8/116.0/116.2/116.4/116.6/116.8/117.0/117.2/117.4/117.6/117.8/118.0/118.2/118.4/118.6/118.8/119.0/119.2/119.4/119.6/119.8/120.0/120.2/120.4/120.6/120.8/121.0/121.2/121.4/121.6/121.8/122.0/122.2/122.4/122.6/122.8/123.0/123.2/123.4/123.6/123.8/124.0/124.2/124.4/124.6/124.8/125.0/125.2/125.4/125.6/125.8/126.0/126.2/126.4/126.6/126.8/127.0/127.2/127.4/127.6/127.8/128.0/128.2/128.4/128.6/128.8/129.0/129.2/129.4/129.6/129.8/130.0/130.2/130.4/130.6/130.8/131.0/131.2/131.4/131.6/131.8/132.0/132.2/132.4/132.6/132.8/133.0/133.2/133.4/133.6/133.8/134.0/134.2/134.4/134.6/134.8/135.0/135.2/135.4/135.6/135.8/136.0/136.2/136.4/136.6/136.8/137.0/137.2/137.4/137.6/137.8/138.0/138.2/138.4/138.6/138.8/139.0/139.2/139.4/139.6/139.8/140.0/140.2/140.4/140.6/140.8/141.0/141.2/141.4/141.6/141.8/142.0/142.2/142.4/142.6/142.8/143.0/143.2/143.4/143.6/143.8/144.0/144.2/144.4/144.6/144.8/145.0/145.2/145.4/145.6/145.8/146.0/146.2/146.4/146.6/146.8/147.0/147.2/147.4/147.6/147.8/148.0/148.2/148.4/148.6/148.8/149.0/149.2/149.4/149.6/149.8/150.0/150.2/150.4/150.6/150.8/151.0/151.2/151.4/151.6/151.8/152.0/152.2/152.4/152.6/152.8/153.0/153.2/153.4/153.6/153.8/154.0/154.2/154.4/154.6/154.8/155.0/155.2/155.4/155.6/155.8/156.0/156.2/156.4/156.6/156.8/157.0/157.2/157.4/157.6/157.8/158.0/158.2/158.4/158.6/158.8/159.0/159.2/159.4/159.6/159.8/160.0/160.2/160.4/160.6/160.8/161.0/161.2/161.4/161.6/161.8/162.0/162.2/162.4/162.6/162.8/163.0/163.2/163.4/163.6/163.8/164.0/164.2/164.4/164.6/164.8/165.0/165.2/165.4/165.6/165.8/166.0/166.2/166.4/166.6/166.8/167.0/167.2/167.4/167.6/167.8/168.0/168.2/168.4/168.6/168.8/169.0/169.2/169.4/169.6/169.8/170.0/170.2/170.4/170.6/170.8/171.0/171.2/171.4/171.6/171.8/172.0/172.2/172.4/172.6/172.8/173.0/173.2/173.4/173.6/173.8/174.0/174.2/174.4/174.6/174.8/175.0/175.2/175.4/175.6/175.8/176.0/176.2/176.4/176.6/176.8/177.0/177.2/177.4/177.6/177.8/178.0/178.2/178.4/178.6/178.8/179.0/179.2/179.4/179.6/179.8/180.0/180.2/180.4/180.6/180.8/181.0/181.2/181.4/181.6/181.8/182.0/182.2/182.4/182.6/182.8/183.0/183.2/183.4/183.6/183.8/184.0/184.2/184.4/184.6/184.8/185.0/185.2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52.0/352.2/352.4/352.6/352.8/353.0/353.2/353.4/353.6/353.8/354.0/354.2/354.4/354.6/354.8/355.0/355.2/355.4/355.6/355.8/356.0/356.2/356.4/356.6/356.8/357.0/357.2/357.4/357.6/357.8/358.0/358.2/358.4/358.6/358.8/359.0/359.2/359.4/359.6/359.8/360.0/360.2/360.4/360.6/360.8/361.0/361.2/361.4/361.6/361.8/362.0/362.2/362.4/362.6/362.8/363.0/363.2/363.4/363.6/363.8/364.0/364.2/364.4/364.6/364.8/365.0/365.2/365.4/365.6/365.8/366.0/366.2/366.4/366.6/366.8/367.0/367.2/367.4/367.6/367.8/368.0/368.2/368.4/368.6/368.8/369.0/369.2/369.4/369.6/369.8/370.0/370.2/370.4/370.6/370.8/371.0/371.2/371.4/371.6/371.8/372.0/372.2/372.4/372.6/372.8/373.0/373.2/373.4/373.6/373.8/374.0/374.2/374.4/374.6/374.8/375.0/375.2/375.4/3



A	AFCEK.K=SPCOTH(FCEAR.JK,NTAFCE)	A	AFERCH.K=SMUCTH(FPRCH.K,IAFCH)
C	NTAFCE=2	A	AFPRCH.K=AFPRCH.K/NFESC
A	IFEA.K=AFCEK.K/CLF.K	C	NFESU=7.5
A	FCEFLU.K=IFEA.K/ILAHF.K	A	NHPRFF.K=IABHL(ITFPA,AFERCH.K,-0.25,0.05,0.01)
A	RFCEFLU.K=FCEFLU.K/NFCEFLU	I	TEFF=0.6/0.4/0.5/0.95/0.93/1/1.05/1.1/1.15/1.2/1.2
C	NFCEFLU=7	NOTE	
A	EZG1.K=IACHL(ITFLO,FFSFLU.K,1.8,2,0.2)	NOTE	FUTLME MARKET (HEDGERS + SPECULATORS)
T	TEEG=1.8/1/1.2/1.1/1.15/1.2/1.25	NOTE	
A	FECK.K=SPCOTH(FECH1.K,1)	L	OPIN.K=CFIN.J+LT*(INSR.JK+LLR.JK+NBR.JK+SHCR.JK)
L	DEVIN.K=DEVIN.J+DT*DEVN.JK	H	OPIN=ISGC*NFRSH
N	DEVIN=50	A	ACFIN.K=SPCOTH(CFIN.K,IACFIN)
R	DEVN.KL=DEVIN.K*FECK.K*NGR.K*ERCATH.K	C	TACFIN=3.5
C	NGR=0.007	A	FATSH.K=ACFIN.K/(ISGC.K*NFRSH)
A	CCFF.K=IABHL(ITCFF,DEVIN.K,5,100,10)	N	FATSH=1
J	ICFF=5.7/0.28/0.67/0.40/0.25/0.20	A	FRSH.K=(ACVSH.K-CFIN.K)/SHCT
A	ATUC.K=IABHL(ITMLC,DEVIN.K,5,100,10)	C	SHCT=3.5
T	IMUC=1/1.15/1.1/1.1/1.12/1.14	A	INSH.K=MAX(FRSH.K,0)
NOTE		A	ISHCR.K=MAX(-FRSH.K,0)
NOTE	***TRADE AND DISTRIBUTION SECTOR***	R	NSR.KL=INSR.K*FPM.K
NOTE		R	SHGR.KL=ISHCR.K*FPM.K
NOTE	TRADERS STOCKS	A	PRLC.K=(REVLC.K-CFIN.K)/LOCT
NOTE		C	LOCT=0.25
L	IQHSGC.K=IQHSGC.L+DT*(AGGER.JK-FUR.JK)	A	INCR.K=MAX(PRLC.K,0)
N	IQHSGC=(NLIYS*ISCSM*DISMFH-0.00)*APUR	A	ILCR.K=MAX(-PRLC.K,0)
L	IQUSGC.K=IQUSGC.L+DT*(UGER.JK-AGGER.JK)	R	NBR.KL=INSR.K*FPM.K
N	IQUSGC=NUR*CTUC	R	LLR.KL=ILLR.K*FPM.K
A	ISGC.K=IQHSGC.K+IQUSGC.K	A	TIFFN.K=SPCOTH(INSR.K+ISHCR.K,0.5)
R	FUR.KL=MIN(IQHSGC.K/CT,ICUR.K)	A	TIFFN.K=SPCOTH(INSR.K+ILLR.K,0.5)
R	AGGER.KL=IABHL(ITCGER,K,ETC)	A	IVCT.K=MIN(TIFFN.K,TIFFM.K)
C	DIUC=0.25	A	FPM.K=IVCT.K/CTIFFN.K,0.01
A	GCR1.K=AFUR.K*(DEYS.K-ISGC.K)/TCT.K	A	FPM.K=IVCT.K/CTIFFM.K,0.01
A	TCT.K=FILE(6,3,5,TIME.K,NFTIM)	A	UCUS.K=(TIFFN.K+TIFFM.K)/DESC
C	NFTIM=300	C	BSCD=1
A	APLR.K=SPCOTH(ICLR.K,IAFF)	NOTE	
C	IAFF=3.5	NOTE	BASIS
A	TIYS1.K=ISGC.K/APLR.K	NOTE	
A	TIYS.K=SMUCTH(TIYS1.K,IAIYS)	A	BASIS1.K=NPRI.K-NPRI.K
C	IAIYS=0.5	A	BASIS.K=SPCOTH(BASIS1.K,IAEAS)
A	DEIS.K=DIYS.K*AFLR.K	C	IAEAS=3.25
A	DIYS1.K=NLIYS*ISCSM*DISMFH.K	A	BASCH.K=(BASIS1.K-BASIS.K)/BASIS.K
C	NLIYS=0.5	A	ABASCH.K=SPCOTH(BASCH.K,TPSCH)
A	DIYS.K=SPCOTH(DIYS1.K,IADTYS)	C	TPSCH=1.25
C	IAIYS=0.5	N	BASCH=1
A	RTYS.K=TIYS.K/DIYS.K	A	REASCH.K=REASCH.K/DESC
NOTE		C	BAS1=2
NOTE	SPC1 AND FLTURE MARKET	A	SHUP.K=IABHL(ITSHF,REASCH.K,-0.05,0.05,0.01)
NOTE		T	ISHL=1.35/1.3/1.2/1.15/1.1/1.05/1.0/0.95/0.9/0.82/0.8
A	ISCSM.K=IABHL(ITSCS,AFPRCH.K,-0.05,0.05,0.01)	A	SHFM.K=IABHL(ITSHF,AFPRCH.K,-0.05,0.05,0.01)
T	ISOS=0.85/0.8/0.75/0.67/1/1/1.03/1.05/1.1/1.12	T	ISFF=0.25/0.23/0.2/0.15/0.125/0
A	DISMFH.K=IABHL(ITSHL,FRISH.K,0.2,0.2)	A	UVSH.K=ISGC.K*NFRSH*SHCH.K+AVLC.K*SHPM.K*SPECAR.K
T	ISSH=1.25/1.22/1.18/1.12/1.05/1.0/0.98/0.95/0.92/0.91/0.99	C	NFRSH=1
A	WPR1.K=KRI.K*PA3S.K*FPM.K	A	ACVSH.K=SPCOTH(ISH.K,IASHPI)
A	ANFRF.K=SPCOTH(NFRF1.K,IAHFR)	C	IASHPI=1.5
N	WPR1=ANFRF*FPM	N	OVSH=CFIN
A	KABS.K=IABHL(ITAES,DCES.K,-5,5,1)	A	LCFM.K=IABHL(ITLCE,REASCH.K,-0.05,0.05,0.01)
T	IAES=0.9/0.91/0.92/0.93/0.98/1/1.02/1.05/1.07/1.09/1.1	T	TLCE=1.15/1.1/1.05/1.02/1.01/1/0.95/0.9/0.85/0.82/0.8
A	FPM.K=IABHL(ITLCE,REASCH.K,-0.05,0.05,0.01)	A	LCFM.K=IABHL(ITLCF,AFPRCH.K,0.05,0.05,0.01)
T	TSIN=0.84/0.65/0.68/0.68/0.9/0.95/0.98/1/1.02/1.04/1.05	T	TLOF=0.05/0.05/0.05/0.20/0.23/1.25
A	ANFRF.K=SPCOTH(NFRF1.K,IAECH)	A	DVLC.K=ACVSH.K*LCFM.K*SPECAR.K
N	NFRCH=3	A	ADVLC.K=SPCOTH(DVLC.K,TALCF)
C	IAFCH=1.5	C	TALCF=0.25
A	AFPRCH.K=AFPRCH.K/NFESC	A	SPICA.K=NSPECA*CLOTA.K
C	NFESC=7.5	C	NSPECA=1
A	FPRCH.K=(WPR1.K-ANFRF.K)/ANFRF.K	NOTE	

```

NOTE QUOTA POLICY- I.C.A.
NOTE
A QUOPR.K=TAGHL(TGTP,AWPR,K,6,12,2)
T QTFR=.5/.5/1/1
A APRCH.K=SMOJH(WFRCH,K,2,5)
A QUOPC.K=TAGHL(TGFC,APRCH,K,-1.05,0,0.01)
T TGPC=.7/.75/.8/.9/.95/1
A QUOTA.K=CLCPR.K*QUOPC.K
NOTE
NOTE BUFFER STOCK POLICY
NOTE
A DEPCS.K=AGCLR.K*IPCYS
A BPRI.K=TAEL(TBLF,AWPR,K,6,24,2)
T TBUF=1.8/1.6/1/1/.98/.96/.94/.92/.90/.90
A SPRJ.K=TAEL(TSLF,AWPR,K,6,24,2)
T TSLF=.2/.4/1/1/1.05/1.1/1.15/1.2/1.25/1.28
A SGCEU1.K=FIEGE(SERI,K,3,DEPCS,K,PCSGC,K)
A BBUA1.K=FIEGE(1,BPRI,K,DEPCS,K,PCSGC,K)
A IBGUP.K=(PCSGC,K-DEPCS,K)*BBUA1.K/BBUCT
A ISGCFB.K=(DEPCS,K-PCSGC,K)*SGCFB1.K/BPSCT
C BBUCT=1E10
C BPSCT=1E10
P BBLR.KL=MIN(1BBLF,K,PCSGC,K/DT)
R SGCFB1.KL=MIN(1SGCFB,K,ELFS,K/DT)
L BUFS.K=BUFS.J+J1*(BBLR,K-SCGFB,K-NEUER,J,K)
N BUFS=0
R NBUCR.KL=ELFS,K/DOEC
NOTE
NOTE INFLT
NOTE
L FCPCP.K=FCPCF.J+J1*FCCR,J,K
N FCPCP=3333
R FPGF.KL=FCPCF,K*FPPG*GROVTH,K
C FPPG=0.014
A GQUFC.K=MAX(1,1E-5,0,1E-6*EXP(0.01*(TIME,K-1890)))
A ICUR.K=F(FCP,K*GQUFC,K
N NPLR=FCPCF*GQUFC
A FROST.K=1+STEP(-YIELC,ITER)*STEP(YIELC,FTFR)
C YIELC=0.4
C ITER=2500
C FTFR=2000
NOTE
R TIME=1320
PLOT YTR=T(0,4009)/AWPR=P(0,40)/PCSGC=S,APRR=R(0,100)/ICUR=U,
X UCER=E(0,20)/ALWEP=A(0,455)
SPEC DT=0.015625/LENGTH=2000/RTTFR=05/PLTFR=1
RUN GROVTH **PCRLD CCEFER SYSTEM**

```

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NOT USED -
IRFM
IPCYS
RIYS

```

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USED 5267 OF 5467 DATA LIST WORDS
477 OF 525 SYMBOLIC TABLE VARIABLES
9 OF 10 MACRO DEFINITIONS
50 PCI CE 2 QUITUT AREA--PRINT/PLOT

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## APPENDIX C

### THE SPECTRAL TECHNIQUE

## APPENDIX C

### THE SPECTRAL TECHNIQUE

#### A. Spectral Method

The following is a brief summary of the power spectral procedure I have used to study the behavior of the coffee economy.

##### 1. Definitions

- a. A series is second order stationary when its mean and variance do not change with time. The theory of spectral analysis requires the use of stationary series. If a series of time exhibit sustained growth, it is good practice to 'detrend' the series.
- b. Autocorrelation Function. Measures the degree of relatedness between a value at time  $t$  and a value at time  $t + \tau$ . If  $\tau$  is zero, autocorrelation is equal to the variance of the time series.

$$C(\tau) = \frac{1}{N-\tau} \sum_{t=1}^N x_t x_{t-\tau}$$

$x_t$  = time series at time  $t$ . (stationary)

$N$  = number of data points. (years, etc.)

$\tau$  = Lag. (in years)

- c. Power Spectra. If a time serie has oscillations, the series can be decomposed into a series of sin and/or cosine terms. The spectral technique shows the contribution to the overall serie-variance of each one of the frequencies



contained in the original data.

$$P(w_j) = \frac{1}{2\pi} \left\{ \lambda_0 C(0) + 2 \sum_{\tau=1}^M \lambda_{\tau} C(\tau) \cos 2\pi f; \pi \right\}$$

$\tau$  = lag in years.

$M$  = number of lags.

$\lambda_{\tau}$  = spectral window.

- d. Spectral Window. As one increases the number of data points, the mean of the estimated spectra approaches the true spectral value; nevertheless, the spectral power is not a consistent estimator: its variance does not decrease with a larger number of data points. A useful way to reduce the variance of the estimated spectra is to take a weighted average of adjacent spectral estimators. The number of estimators to smooth, and their weight are given by the 'spectral window.'

A too wide spectral window, i. e. too many adjacent estimators to weight, will produce a rather smooth spectra (high stability); on the other hand, this type of spectra tends to omit some of the frequency bands embodied within the time series, which gives a too low fidelity. Therefore, a way to obtain a good spectral estimator is to choose a window not too wide as to lose fidelity, and not too narrow as to lose stability. This is the purpose of the 'closing window technique,' outlined later.

There are several types of spectral windows. In this research I have used two different windows. One, the Parzen window has given a more stable

response to very low frequencies. The other, the Bartlett window produced very good response at high frequencies, but it lacked resolution at very low frequencies. I used the two techniques to improve credibility at very low frequencies (more than 15 years of period).

Parzen window:

$$\lambda_{\tau} \begin{cases} = 1 - 6(\tau/M)^2 + (\tau/M)^3 & 0 \leq \tau/M \leq 0.5 \\ = 2(1 - (\tau/M)^3) & 0.5 < \tau/N \leq 1 \\ = 0 & \tau/N > 1 \end{cases}$$

Bartlett window:

$$\lambda_{\tau} \begin{cases} = 1 & 0 < \tau < M \\ = \frac{1}{2} & \tau = 0, M. \end{cases}$$

- e. Spectral Plot. The spectral estimators appear at equally spaced frequencies going from 0 to 0.5 cycles per year. The presence of a peak indicates the possible existence of a cycle in the time series. Spectral estimators follow a  $\chi^2$  distribution<sup>1)</sup> with k degrees of freedom depending upon the number of data points N, and the number of lags M:  $k = 2N/M$ . Therefore, confidence bands can be plotted to check for the significance of each peak. For example,

$$P_r \left\{ \frac{\chi^2_{\alpha/2}}{k} \leq \frac{\hat{Q}_j}{\hat{\Psi}_j} \leq \frac{\chi^2_{1-\alpha/2}}{k} \right\} = \alpha$$

<sup>1)</sup> If the serie is stationary and follows a Gaussian process; practitioners of Spectral Analysis claim that the estimators closely follow a  $\chi^2$  distribution even in the case in which the process does not follow a Gauss (normal) distribution.

where  $\Phi_j$  is the True spectra and  $\Psi_j$  is the estimated spectra. The confidence band in a semilog paper is then given by:

$$\log \Psi_j - \frac{\chi^2_{\alpha/2}}{k} \geq \Phi_j \geq \log \Psi_j + \frac{\chi^2_{1-\alpha/2}}{k}.$$

- f. Number of Lags M. A very crude spectral plot could be obtained with 80 data points. Jenkins suggests at least  $N=100$ ; generally, a good spectra could be obtained with  $N=200$  points.

For the Bartlet window the number of lags M should be not more than  $N/3$ , and not less than  $N/6$ .

The selection of lags M when one uses the Parzen window should be made as follows:  $N \geq 2M \geq 3F$ , where F is the number of frequency bands used to calculate the spectral.

#### B. The Closing Window Technique

- a. Make the band-width of the spectral window progressively smaller. This is done by increasing the number of lags (M) used. With 150 years of coffee prices, I chose lags varying from 20 to 50 years.
- b. The power spectra will change strongly at first, then as the number of lags are augmented the spectra will tend to settle down. Further narrowing of the window will tend to create a too noisy pattern. With yearly coffee data the plot generally settles down at about 35 or 40 lags.
- c. The proper number of lags to start the process may be selected from the autocorrelation function. If there are cycles in the series, this function will

exhibit oscillations at some lags. Coffee data showed these oscillations at 20, and 35 lags.

### C. Harmonic Frequencies

A good method to gain confidence about the presence of a cyclic movement is to look for harmonics of the suspected frequency. Harmonic cycles have a frequency which is a multiple of the frequency sought. On the spectral plot, a harmonic has a frequency of 'around' a multiple of the other fundamental frequency. However, a frequency (peak) is a harmonic if its power spectra is less than the power at the fundamental.<sup>2)</sup>

- \* If a peak at a frequency  $f$  is not statistically significant, but harmonics  $2f$ ,  $3f$ , ... exist, the frequency component  $f$  may be really in the data time series.
- \* It is extremely unlikely that a time series will contain a frequency  $f$  with no harmonics.
- \* The confidence bands drawn upon the spectral plot, test the significance of each one of the different frequencies. To my knowledge, there is no available statistical test to show how significant is a fundamental frequency and its harmonics when taken together at a time.

The previous notes on spectral techniques have been summarized from several authors. The references are given in the Bibliography, section on Spectral Analysis.

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<sup>2)</sup> Not totally true for certain modulated radio waves. See [49].

## APPENDIX D

### SOURCES OF INFORMATION

## SOURCES OF INFORMATION

<u>Variable</u>	<u>Units</u>	<u>Years</u>	<u>Region(s)</u>	<u>Source</u>
Production	Annual	1900-1973	World; producers	[2]; [5]; [8]
Exportable Production	Annual	1900-1973	World; producers	[2]; [5]; [8]
Exports (Bags)	Annual	1910-1973	World; producers	[2]; [5]; [8]
Export Value (\$US)	Annual	1947-1973	World; producers	[13]
Domestic Usage	Annual	1948-1973	Brazil, Colombia	[5]; [8]
Producers' Stocks (Carry-Over)	Annual	1948-1973	World, Brazil, Colombia	[5]; [8]; [13]
U.S. Stocks	Quarterly	1958-1974	U.S.A.	C.E.A.; Commodity Exchange Authority (CEA)
U.S. Imports	Quarterly	1958-1974	U.S.A.	CEA
U.S. Roasting	Quarterly	1958-1974	U.S.A.	CEA
U.S. End Consumption	Annual	1958-1974	U.S.A.	[32]
European Consump. (Imports)	Annual	1931-1946 1947-1972	Europe	[5]
World Capacity (Trees/Land)		1942-1972	Brazil (partial data) }	[5]; [13]
Avg. Price (¢/pd.) (Spot at N. Y.)	Annual Monthly	1825-1973 1930-1973	Total avg.; per type of coffee	[2]; [5]
Avg. Future Price (at N. Y.)	Monthly	1930-1973	Santos type 'C' contract	[2]
Price differentials	Annual	1952-1972	Between 3 types of coffee	[5]
Labor Force in Coffee	Men	1946-1970	World Colombia	[29]; [30]; [31] [16]
Average Yields	Kg/Tree/Yr		Colombia Brazil	[16] [24]
Producer Costs	\$/Yield		Colombia Brazil	[16] [24]

<u>Variable</u>	<u>Units</u>	<u>Years</u>	<u>Region(s)</u>	<u>Source</u>
Volume of Transactions at New York Coffee and Sugar Exchange	Annual	1955-1972	U.S.A.	[2]

## APPENDIX E

### THREE-AT-A-TIME EXPERIMENTAL DESIGN



## APPENDIX E

## THREE-AT-A-TIME EXPERIMENTAL DESIGN

Simulation Run No.	Parameters							Response Period, Amplitude, etc.
	P1	P2	P3	P1 x P2	P1 x P3	P2 x P3	P1 x P2 x P3	
1	-	-	-	+1	+1	+1	-1	
2	+	-	-	-1	-1	+1	+1	
3	-	+	-	-1	+1	-1	+1	
4	+	+	-	+1	-1	-1	-1	
5	-	-	+	+1	-1	-1	+1	
6	+	-	+	-1	+1	-1	-1	
7	-	+	+	-1	-1	+1	-1	
8	+	+	+	+1	+1	+1	+1	
9	NV	NV	NV	0	0	0	0	

1. Note: (+, -) ~ (+ $\chi$ %, -  $\chi$ %),  $\chi$  is fixed percent change in all parameters.

NV. ~ Normal Parameter Value

2. Regression to determine % explained by the main effects

<sup>1)</sup>Experiment designed by Dr. W. Low.

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